This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

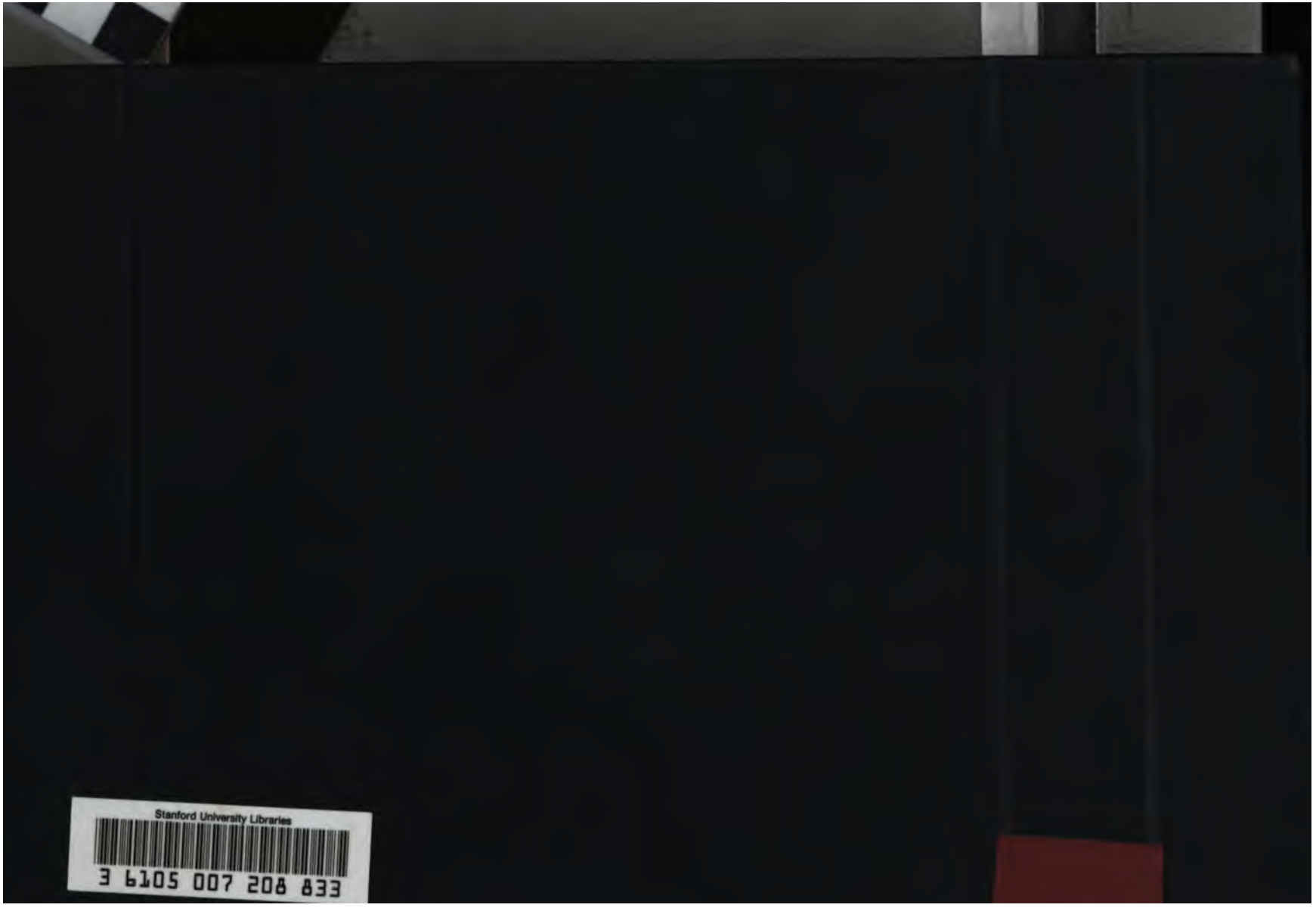
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


Stanford University Libraries
3 6105 007 208 833

7512

NON-CIRCULATING

Chas. T. Scott

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL .ENGINEERS.

JANUARY TO JUNE 1903.

VOL. XXI.

PUBLISHED BY
THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
95 LIBERTY STREET,
NEW YORK CITY, U. S. A.
1904.

Copyright 1903
by the
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

98214

Press of McILROY & EMMET, 22 Thames Street, New York.

OFFICERS AND BOARD OF DIRECTORS.

1902-1903.

PRESIDENT.

CHARLES F. SCOTT.
Term expires 1903.

JUNIOR PAST-PRESIDENTS.

CARL HERING. CHARLES P. STEINMETZ.

VICE-PRESIDENTS.

Terms expire 1903.	Terms expire 1904.
DR. MICHAEL I. PUPIN.	BION J. ARNOLD.
DR. SAMUEL SHELDON.	C. O. MAILLOUX.
GEORGE F. SEVER.	DR. SCHUYLER S. WHEELER.

MANAGERS.

Terms expire 1903.	Terms expire 1904.	Terms expire 1905.
JOHN J. CARTY.	JOHN W. LIEB, JR.	GANO S. DUNN.
W. S. BARSTOW.	PROF. W. E. GOLDSBOROUGH.	E. H. MULLIN.
RALPH D. MERSHON.	COL. SAMUEL REBER.	CHARLES A. TERRY.
CALVIN W. RICE.	R. T. LOZIER.	TOWNSEND WOLCOTT.

TREASURER.	SECRETARY.
Terms expire 1903.	
GEORGE A. HAMILTON.	RALPH W. POPE,
463 West Street, New York.	95 Liberty Street, New York.

PAST-PRESIDENTS.

DR. NORVIN GREEN, 1884-5-6.
FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
PROF. ELIHU THOMSON, 1889-90.
PROF. W. A. ANTHONY, 1890-91.
ALEX. GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
DR. EDWIN J. HOUSTON, 1893-4-5.
DR. LOUIS DUNCAN, 1895-6-7.
DR. FRANCIS B. CROCKER, 1897-8.
DR. A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-01.
CHARLES P. STEINMETZ, 1901-2.

COMMITTEES AND LOCAL SECRETARIES.

STANDING COMMITTEES.

Executive Committee.
CHARLES F. SCOTT, Ch'm.
JOHN J. CARTY.
GANO S. DUNN
GEO. A. HAMILTON.
CALVIN W. RICE.
RALPH W. POPE.

Committee on Papers.
DR. S. SHELDON, Chairman
BION J. ARNOLD.
T. C. MARTIN.
CHAS. P. STEINMETZ.
H. G. STOTT.

Library Committee.
WM. D. WEAVER, Ch'm.
GANO S. DUNN.
W. J. JENKS.
CHARLES E. KNOX.
LEONARD WALDO.

Committee on Finance.
JOHN J. CARTY, Chairman.
W. S. BARSTOW.
CALVIN W. RICE.

Board of Examiners.
WM. MAVER, JR., Ch'm'n.
F. W. ROLLER.
HENRY A. LARDNER.
L. B. STILLWELL.
TOWNSEND WOLCOTT.

Editing Committee.
GANO S. DUNN, Chairman.
EDWARD CALDWELL.
HENRY A. LARDNER.

SPECIAL COMMITTEES.

Local Organizations.
CALVIN W. RICE, Ch'm'n.
GANO S. DUNN.
P. G. GOSSLER.
W. E. GOLDSBOROUGH.
SAMUEL SHELDON.

Membership Committee.
W. S. BARSTOW, Chairm'n.
J. J. CARTY.
W. E. GOLDSBOROUGH.
SAMUEL REBER.
W. D. WEAVER.

Building.
CALVIN W. RICE, Ch'm.
WM. D. WEAVER.
C. O. MAILLOUX.
DR. S. S. WHEELER.

Reception.
T. C. MARTIN, Chairman.
WILLIAM J. HAMMER.
E. H. MULLIN.
B. GHERARDI, JR.
W. S. BARSTOW.
W. HAND BROWNE.
ARTHUR WILLIAMS.
F. C. BATES.
CALVERT TOWNLEY.

Collection of Data on Transmission.
R. D. MERSHON, Chairm'n.
F. O. BLACKWELL.
C. C. CHESNEY.
P. M. LINCOLN.
R. S. MASSON.

National Electric Code.
A. E. KENNELLY, Ch'm.
L. A. FERGUSON.
P. G. GOSSLER.
F. A. C. PERRINE.
C. P. STEINMETZ.
ARTHUR WILLIAMS.
C. J. H. WOODBURY.

Theses.
GEO. F. SEVER, Ch'm.
W. S. BARSTOW.
F. W. ROLLER.

Standardization.
PROF. H. J. RYAN, Ch'm.
H. W. BUCK.
JOHN F. KELLY.
R. D. MERSHON.
J. S. PECK.
PROF. E. B. ROSA.
CHAS. P. STEINMETZ.

LOCAL HONORARY SECRETARIES.

RICHARD H. PIERCE,
1409 Manhattan Building, Chicago.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

GEORGE P. LOW,
320 California St., San Francisco, Cal.

EDWARD P. BURCH,
1210 Guaranty Building,
Minneapolis, Minn.

H. F. PARSHALL,
Salisbury House, London Wall, E. C., London, Eng.

PROF. ROBERT B. OWENS,
McGill University, Montreal, P. Q.

CLARE F. BEAMES,
City of Mexico.

W. G. T. GOODMAN,
Dunedin, New Zealand.

JOHN S. PECK,
P. O. Box 911, Pittsburg Pa.

CONTENTS.

FRONTISPIECE.—Portrait of Charles F. Scott, President of the INSTITUTE.

TELEPHONY.

REGULAR MEETING, NEW YORK, JANUARY 23, 1903.

The Telephone Switchboard.—Introduction by President Scott..... 1
The Evolution of the Telephone Switchboard.—By Thomas D. Lockwood..... 3
An Automatic Telephone Operator.—By William J. Hammer..... 31
Discussion at New York, on The Telephone Switchboard, by Thomas D. Lockwood, Samuel Sheldon, J. J. Carty, F. A. Pickernell, B. Gherardi, Jr., E. F. Sherwood, G. C. Allen, F. E. Kinsman..... 55

MEETING AT CHICAGO, MAY 19, 1903.

Some Features of Telephone Traffic and Their Effect on Service.—By J. G. Wray..... 73
Concerning the Telephone Engineer.—By S. G. McMeen..... 81

MEETING AT UNIVERSITY OF ILLINOIS, FEBRUARY 7, 1903.

Discussion on Telephony..... 84

MEETING AT PITTSBURG, FEBRUARY 5, 1903.

Discussion on Telephony, by S. P. Grace, Charles Bradley,.. 84
Communication after adjournment, by Sidney H. Browne.... 90
The Arcophone.—By R. A. L. Snyder..... 93

ANNUAL DINNER OF THE INSTITUTE.

AT NEW YORK, FEBRUARY 9, 1903.

Speech by President Charles F. Scott..... 97
Speech by Andrew Carnegie..... 105
Speech by Schuyler S. Wheeler..... 110
Speech by R. R. Bowker..... 114
Speech by J. S. Billings..... 118
Speech by Theodore L. De Vinne..... 120
Speech by James C. Bayles..... 124

RAILWAY TRAIN LIGHTING.

REGULAR MEETING, NEW YORK, FEBRUARY 27, 1903.

Introduction.—By President Scott..... 129
An Electric Car Lighting System.—By W. L. Bliss..... 133
Axle Lighting.—By Elmer A. Sperry..... 155
An Axle-Light System of Train Lighting.—By Arthur J. Farnsworth. 163
Some of the Problems of Electric Train Lighting.—By George D. Shepardson..... 173
Discussion at New York, on Railway Train Lighting, by Chas. F. Scott, H. S. Carhart, Lamar Lyndon, W. L. Bliss, Max von Recklinghausen, George W. Blodgett, C. W. Hogan, A. J. Farnsworth, Mr. Lockwood, Hy. G. Stott, Elmer A. Sperry, W. N. Smith, James F. McElroy..... 179
Communication after adjournment, by J. R. Bibbins..... 193

MEETING AT BOSTON, MARCH 26, 1903.

A System of Electric Lighting for Cars.—By James F. McElroy..... 197

MEETING AT MINNEAPOLIS, MARCH 6, 1903.

Discussion on Railway Train Lighting..... 208

MEETING AT PHILADELPHIA, MARCH 9, 1903.

Discussion on Railway Train Lighting, by Carl Hering, W. L. Bliss, Chas. B. Dudley, Ralph W. Pope, Hugh Lesley, Cornelius W. Woodward, Chas. E. Hewitt, W. C. L. Eglin, Chas. J. Reed, Philip L. Spalding, John B. Klumpp..... 209

MEETING AT PITTSBURG, MARCH 12, 1903.

Discussion on Railway Train Lighting, by P. M. Lincoln, J. S. Peck, N. W. Storer, A. H. Masters, B. B. Abry, J. M. Campbell.. 220

MEETING AT SCHENECTADY, MARCH 17, 1903.

Discussion on Railway Train Lighting, by A. H. Armstrong, C. P. Steinmetz, W. I. Slichter..... 224
Communication after adjournment, by R. Neil Williams.... 226

HIGH-TENSION TRANSMISSION LINES.

MEETING AT NEW YORK, MARCH 27, 1903.

Introduction.—By President Scott..... 229

Mechanical Specifications of a Proposed Standard Insulator Pin.—By Ralph D. Mershon..... 223

The Testing of Insulators.—By F. O. Blackwell..... 239

Transposition and Relative Location of Power and Telephone Lines.—By P. M. Lincoln..... 245

Burning of Wooden Pins on High-Tension Transmission Lines.—By C. C. Chesney..... 253

Model Showing Distribution of Electromotive Force and Current along a Single-Phase Alternating-Current Transmission Line.—By W. S. Franklin..... 261

Discussion at New York, on High-Tension Transmission, by Ralph D. Mershon, M. H. Gerry, Jr., Wm. R. C. Corson, C. L. Cory, A. L. Huntington, W. N. Smith, P. H. Thomas, Samuel Sheldon, P. M. Lincoln, T. W. Shock, F. N. Waterman, C. C. Chesney, W. L. Waters, C. E. Skinner, C. O. Mailloux, H. W. Buck, Carl L. de Muralt, Philip Torchio, W. S. Franklin..... 263
Communication by M. H. Gerry, Jr., entitled A Note on Line Insulation for High Voltage..... 295
Communication after adjournment, by W. N. Smith..... 295
Communication after adjournment, by J. R. Armstrong.... 296
Communication after adjournment, by F. S. Woodward.... 296
Communication after adjournment, by Henry Floy..... 297

MEETING AT MINNEAPOLIS, APRIL 3, 1903.

Discussion on High-Tension Transmission..... 298

MEETING AT SCHENECTADY, APRIL 7, 1903.

Discussion on High-Tension Transmission, by F. A. C. Perrine 299

MEETING AT PHILADELPHIA, APRIL 6, 1903.

Discussion on High-Tension Transmission, by Mr. Hodges, P. M. Lincoln, Carl Hering, Washington Devereaux, Charles Hewitt, James T. Hutchings H. F. Sanville, Thos. Spencer.... 301

MEETING AT CHICAGO, APRIL 7, 1903.

Discussion on High-Tension Transmission, by W. G. Carlton, Ernest Gonzenbach, H. H. Wait, Mr. Hatch, J. R. Cravath.... 307

MEETING AT PITTSBURG, APRIL 9, 1903.

Discussion on High-Tension Transmission, by C. E. Skinner, S. P. Grace, B. Frankenfield, Mr. Bedell, P. M. Lincoln, H. Etheridge, P. H. Thomas, J. S. Peck, C. F. Scott..... 312

RADIOACTIVE SUBSTANCES.

MEETING AT NEW YORK, APRIL 17, 1903.

Introduction.—By President Scott..... 327
Radium and Other Radioactive Substances with a Consideration of Phosphorescent and Fluorescent Substances. The Properties and Applications of Selenium and the Treatment of Disease by the Ultra-Violet Light.—By William J. Hammer..... 331

TENDENCIES OF CENTRAL STATION DEVELOPMENT.

MEETING AT NEW YORK, APRIL 24, 1903.

Introduction.—By President Scott..... 403
Economical and Safe Limits in the Size of Central Stations.—By H. A. Lardner..... 407
Safety Devices in Central Stations and Sub-stations.—By Philip Torchio 417
Multiple versus Independent Operation of Units and Central Stations. —By Peter Junkersfeld..... 425
Discussion at New York, on Central Station Development, by Chas. F. Scott, Hy. G. Stott, Herbert A. Wagner, F. A. Waldron, Edw. Sniffin, Jno. W. Lieb, Townsend Wolcott, W. S. Rugg, A. V. Abbott, Peter Junkersfeld, H. A. Lardner, Ph. Torchio, Ph. K. Stern..... 441

MEETING AT CHICAGO, MAY 5, 1903.

Discussion on Central Station Development, by B. J. Arnold, W. L. Abbott, Peter Junkersfeld, H. B. Gear, W. G. Carlton, J. R. Cravath..... 457
Communication after adjournment, by Carl Schwartz..... 461

MEETING AT PITTSBURG, MAY 11, 1903.

Discussion on Central Station Development by Francis Hodgkinson, H. Etheridge, C. W. Rice, P. M. Lincoln, Chas. F. Scott..... 462

MEETING AT ST. LOUIS, MAY 16, 1903.

Discussion on Central Station Development, by E. D. Matlack, Frank Welz..... 467

MEETING AT PHILADELPHIA, MAY 11, 1903.

Discussion on Central Station Development, by W. C. L. Eglin, H. A. Foster, Carl Hering, Chas. Hewitt, Ph. Torchio, Paul Spencer..... 469

MEETING AT MINNEAPOLIS, MAY 1, 1903.

Discussion on Central Station Development..... 476

ANNUAL BUSINESS MEETING.

HELD AT NEW YORK, MAY 19, 1903.

Remarks by President Scott..... 479
Report of Board of Directors for the Year Ending April 30, 1903..... 480
Resumé of Membership..... 484
Resignations during the Year..... 484
Deaths during the Year..... 484
Secretary's Balance Sheet..... 485
Treasurer's Report..... 486
Teller's Report..... 486
Union Engineering Building..... 486

ALTERNATING-CURRENT MACHINES.

MEETING AT NEW YORK, MAY 19, 1903.

The Experimental Basis for the Theory of the Regulation of Alternators.—By B. A. Behrend..... 497

A Study of the Heyland Machine as Motor and Generator.—By Comfort A. Adams..... 519

The Compounding of Self-Exciting Alternating-Current Generators for Variation in Load and Power Factor.—By A. S. Garfield..... 569

Discussion at New York, on Alternating-Current Machines, by Chas. F. Scott, B. A. Behrend, Comfort A. Adams, Gano S. Dunn, W. L. Waters..... 578

Communication after adjournment, by J. R. Armstrong..... 582

Communication after adjournment, by Marius Latour..... 583

MEETING AT PITTSBURG, JUNE 4, 1903.

Discussion on Alternating-Current Machines, by P. M. Lincoln, V. Karapetoff, Mr. Schmit, J. S. Peck, E. M. Olin..... 586

ALTERNATING-CURRENT THEORY.

MEETING AT SCHENECTADY, MAY 18, 1903.

A Discussion of Some Points in Alternating-Current Theory.—By W. S. Franklin..... 589

A paper read at the 173d Meeting of the American Institute of Electrical Engineers, New York, January, 23, 1903.

THE TELEPHONE SWITCHBOARD.

INTRODUCTION BY PRESIDENT SCOTT.

Imagination is outdone by invention. The inventor and the engineer accomplish more than the weird story-teller or the far-seeing prophet can portray. For centuries conditions have been imagined or a future pictured in which men were endowed with superhuman attributes. Ancient mythology made the swift-winged Mercury the messenger of the gods. Fairies have been given magical powers and charms, and there have been legends of seven-league boots; but all the flights of imagination, at least until electricity came to its aid, are transcended by the evolution of the telephone during the past quarter century. What would have been thought of a young man fifty years ago had he predicted that the time would come when he at his office desk or at his home, could in a moment's time be in conversation with any one of a thousand or of ten thousand or of a hundred thousand or of three-quarters of a million people in his own city or scattered anywhere within a thousand miles in city, town, hamlet or country. The thing has become so common that it has ceased to be a wonder or a marvel. But it underlies modern existence. It is a part of our business method, our commercial system, our social life. It has modified and modernized our methods, it has enormously accelerated the rate at which men can do work. The communication between the home and the store, the home and the office, the communication from office to office, the communications between the departments of a large organization and between office and store and factory—in fact, almost every species of communication, which formerly required hours or days of time expended for personal travel and for interview, or for letter-writing—all these things have been revolutionized by the evolution of the telephone. High-speed tools are modernizing the machine-shop—increasing output and reducing cost; the

telephone is the high-speed tool of the commercial world—it facilitates organization and coöperation, it increases output by doubling the work a man can do. It is one of the essential conditions of the increasing and enlarging activity of the present years.

The telephone is not merely an invention. The elements are the work of the inventor, but the great system of conductors and connections are more properly the work of the engineer—of him who applies the scientific discoveries of the inventor and embodies them into useful apparatus in an operative system. We may discard the marvel by which the voice through the infinitesimal current is reproduced at a far distant place and consider simply the mechanical apparatus by which the simple transmitters, receivers and conductors are combined into one great interchangeable flexible system. What are the means by which the wires from my telephone may in a moment be connected to the wires of any one of a hundred thousand telephones at the same moment that a thousand others are being connected in the same great system? Here it is that the work of the mechanical designer and the engineer have supplemented that of the inventor. Here it is that we see how the minutest details must be specialized and elaborated to bring the work of the inventor to the service of the people. True, there is the magic of electricity, but there has been also most elaborated scientific investigation coupled with the most exacting mechanical design in order to produce great results.

The telephone switchboard has not sprung into existence fully equipped for its requirements. It has been an evolution. The requirements themselves have been an evolution; an evolution in a field quite apart from that in which dynamos and motors and electric lighting and power transmission have held sway. The telephone evolution may have attracted less attention; it has been less heralded, and the details and methods are less generally known. The apparatus and the methods used in the modern telephone system have not come as the result of inspiration or luck, but they have followed along the lines of scientific evolution. The advance has been step by step, but the steps have followed rapidly, and in a score of years a system has been evolved, almost perfect in its operation, of colossal extent and marvelous in detail. It has brought about in these few years changes in our social and commercial methods greater than have occurred throughout centuries in the past.

A paper read at the 172nd Meeting of the American Institute of Electrical Engineers New York, January 23, 1903.

THE EVOLUTION OF THE TELEPHONE SWITCHBOARD.

BY THOMAS D. LOCKWOOD.

A historic account of the development of the telephone exchange, and an analysis of the mechanical and electrical features of telephone switchboard apparatus from 1877 to date.

Two poets, as far apart chronologically as Lucretius and W. S. Gilbert, have sung the praises of the magnet; and the muse of Cowper has not disdained to celebrate such homespun and ordinary household gods as the sofa and the timepiece, and though the telephone switchboard is not a prominently manifested effect of a great force of nature, and not even a household god, it is in such close alliance with more than one of nature's forces, and stands in such faithful attendance to some of our home divinities, that it well merits more attention from the chronicler than it has thus far received.

The highly organized and highly specialized collocation of apparatus that we now term the telephone switchboard, and which is at present employed in the large central stations of our great city exchanges, such as the Cortlandt street central station in New York, and the main central station in Boston, as a means of carrying out the varied and complex functions required at the central station end of a great number of telephone circuits, has doubtless been seen by, and is familiar to many of you; while probably many more have a speaking acquaintance with it, and have considered it with more or less attention.

Its present condition of relative perfection and high efficiency has, however, been attained only after persistent effort, and after many previous attempts, each in its result showing some progress, but each indicating or developing faults and errors to be overcome by its successor.

At the outset of the telephone exchange business every telephone man had to learn his trade. Even the telephone itself

was but two years old, and except Professor Bell and his immediate associates no one knew anything worth mentioning about that instrument or its capabilities. None certainly could foresee what direction the lines of improvement would take; and none could foreshadow the extent of growth which might be expected for such systems.

But notwithstanding the general ignorance, the telephone exchange came into existence; and with it necessarily came something for the convenient connection and disconnection of lines. It would be profitless to devote much time to the earliest switchboards of all. It is enough to say that during what I may call the dark ages of exchange telephony, the switching appliances were of three different types; and this largely because in the beginning there were three different classes of incipient telephone engineers. The electrical expert coming into the telephone exchange from the ordinary or regular telegraphic systems, naturally pinned his faith to the standard pin switchboard usually employed by the telegraph companies. Those coming from special systems such as the stock quotation printing, burglar alarm and district messenger companies as a rule exhibited a preference for a switchboard whereon the lines had brass terminal plates with plug holes in them, the same to be united by switch-cords armed at both ends with plugs to be inserted in these holes. The telephone men with no previous telegraphic experience of any kind, chiefly those who had grown up round Professor Bell, and under the influence of his immediate associates, were inclined to eclecticism as regards the rival claims to merit, of pin and cord switchboards; but believed in dividing the work of interconnecting and its sub-operations between two or more operators, of whom one set received calls and made the required connections on the switchboard proper; while the others acting in some sort as dry nurses to the subscribers, supervised the communication, sent outgoing calls and encouraged the subscribers to talk.

As a means of receiving calls, some of the pioneer switchboards had a row of electric bells mounted along the top of the board, one for each line, and in such cases there was a normally connected battery, supplying current to a group of lines, the bells being operated by break keys at the substation. Still others had closed circuit annunciators, one for each line, these also being operated by breaking the circuit. Soon, however, the battery was discarded, being superseded by magneto generators at the substations, and then of course open circuit annunciators were

substituted at the central stations. It is of interest to note that the battery, discarded twenty years ago as a cumbersome adjunct, is now one of the most cherished features of central station practice; and all through the history of telephone practice, thus it has proved, that appliances and methods discarded as being inferior at certain stages, have been revived under the stimulus of more favorable conditions and advanced knowledge, and have turned out to be useful in the highest degree.

Before 1880, it had become decidedly manifest that some kind of telephone exchange service must be provided during the night. Few exchanges could afford to keep regular operators constantly at work later than ten o'clock. Consequently, a compromise measure was resorted to, and a night operator was stationed in the central office with permission to sleep; and a night alarm consisting of a loud sounding vibrating bell was provided, connected in a local circuit extending in one direction to a bar constituting a stop on which all annunciator drops might fall, and in the other direction to all of the several drops; so that the operation of any annunciator would ring the bell and awaken the operator. This contrivance is still employed in many small exchanges, and enables exchanges to remain operative at night, while as yet the number of subscribers is so small that a night attendant could not be otherwise afforded. Before this date it was also discovered that while the Western Union pin switchboard unmodified might be a satisfactory switchboard for telegraph offices, it was decidedly unsatisfactory for a telephone exchange. It was slow; it was not easily manipulated; it did not easily lend itself to coöperation with the other exchange apparatus; and it occupied considerable space. In brief, it had been devised for the needs of a telegraph office where a switchboard is but an incidental device arranged mainly to facilitate the connection of any particular line with any particular instrument or battery; and only on rare occasions to connect one line with another. In telephonic work, however, the function of the exchange is the interconnection of one line with another at all times and nothing else. To paraphrase the well-known couplet of Byron, the switchboard is in the telegraph office a thing apart; it is of the telephone exchange the whole existence.

Summarizing these considerations, it may be truly said that the main difference between the telephone exchange switchboard and that of the telegraph office, or any preceding system, was that whereas the manipulation of the telegraphic switchboard

involves the employment of experts, the telephonic switchboard is so designed that it may readily be operated with great celerity by persons who are not only inexpert, but who actually are entirely ignorant of the nature of the operations which they continually perform.

In 1880 the most representative exchanges had switchboards employing long brass or painted connection strips extending from end to end of the board. In New York as elsewhere, switchboards possessing this feature were employed, but there the preferred switchboard was operated by cordless plugs; the cross strips having a number of plug-holes, while a series of vertical conductors representing the subscribers' lines crossed these horizontal strips at a right angle in the rear of the board, these being spring plates overlapping the holes. Thus, when the plug was inserted in the hole of the cross-strip, it made a good rubbing connection with the spring line strip behind. The cross strips were arranged in pairs and were connected by looping wires to an adjacent table fitted with an operator's telephone and a call generator where connections were supervised, and any two lines concerned in a connection were attached by separate plugs to the two strips of a pair respectively.

In other cities the long brass strips were employed without any vertical line strips, each line being represented by a single spring-jack only. When such was the case the connection could not be effected by simple plug connectors; but necessitated the employment of cords fitted at one end with flat wedges to enter the spring-jacks, and at the other with plugs to enter the holes in the crossing strips. In this case, also, the crossing strips were looped to tables where the connections were supervised by operators.

In these systems an incoming call announced itself by the fall of an annunciator. One of a number of switchmen (so-called) provided with a magneto telephone connected with a loop-plug adapted to fit the spring-jack of the calling line, would plug in and receive the order. The same switchman then united the calling line and the line wanted, to the two cross-strips of some particular pair; and thus connected them not only with one another, but also to the table of some particular operator. The operator notified of the connection thus made, would first send a call current from a generator to the subscriber wanted, and receive his answer orally, and would then unite the two lines through a disconnecting drop. It was usually a matter of diffi-

culty to get the two subscribers to talk with one another, and the operator had, as it were, to coax them along.

An early appearing difficulty with this class of switchboard was, that the connecting strips running as they did from end to end of the switchboard took up an amount of space entirely disproportionate to their usefulness. Accordingly, they were later severed at one or more places, so that a number of connecting strips on the same horizontal plane might be severally connected to the same or different operators' tables.

Although the pin switchboard unmodified had not proved itself to be desirable, a new form of it was evolved during the year 1880, which considerably prolonged its lease of life. It was in desk form with a vertical part behind the desk, and in it the lines were represented by corrugated strips of brass mounted on edge, and crossed without touching, by a number of other corrugated brass strips also mounted on edge; the connections of any two line strips with any one or two cross strips being made by sheet brass connection plugs adapted for insertion at the intersections.

This switchboard was arranged in a number of groups, each to be presided over by a single operator, performing all of the several functions in the connection of lines; and several cross strips were assigned to her for local connections, while a certain number of others were extended to each of the other sections. An attempt about this time was made to classify lines by the trades, professions or vocations of the subscribers, but this failed by reason of the fact that it turned out that very few subscribers cared to communicate with others in the same business.

One horizontal strip of each group was connected with an earth branch including the telephones of the operator of such group, and another such strip was in like manner connected with the magneto generator of the same operator. Thus, by inserting a connection plug at the intersection of any line plate with the operator's telephone or generator cross strip, and performing any other requisite operation, the operator might converse with the subscriber, or send a call.

This switchboard was of low initial cost, and was, therefore, suited to the times, for it had already been discerned that the income of a telephone exchange was not by any means all profit. It was, however, mechanically and electrically bad. It occupied considerable space and the electrical connections made by its plugs were imperfect. There is, indeed, a legend than an electrical engineer was visiting a certain central station, where this

switchboard was exhibited with pride, and asked whether the plugs made good connections. When assured that they did, it is said that he blew at the switchboard with the result that some forty or fifty of the plugs were blown out of place.

Meanwhile it had dawned upon a number of the telephone men of the day that the separate call generator at each switchboard adapted for manipulation by the operator, might be profitably superseded by a common generator supplying the entire central station, and having branches to each operator's position, and keys whereby the current might be transmitted over any line at will. This sometimes, and especially where power could not conveniently be applied, took the form of a calling battery supplemented by an automatic electro-magnetic pole-changer; but was preferably an alternating current magneto-electric generator, driven by any suitable power.

It will be seen that up to this time, indeed up to about 1884, there was no uniformity in switchboard apparatus; and there was no standard switchboard.

It had been ascertained by experience that the function of the central station was not merely to connect and disconnect telephone lines. It was far more complex. Calls were to be received, and signal receiving appliances therefore were to be provided. Calls were to be answered and orders received, and for this purpose means were requisite to connect the operators' telephones with a call-originating line. Before connection could be established between a calling and a wanted line, it was essential to ascertain whether such wanted line might not be already engaged, and for this ready means of communication between the operators was necessary. If occupied, the fact had to be reported to the call originator. If not, a call signal had to be sent to the station wanted; and thus means for sending signals was also essential; and finally some device had to be rearranged for the indication and reception of ring-off signals.

Most of these appliances had of course been associated in a kind of haphazard fashion with switchboards from the beginning; but not until about this time, was any attempt made to incorporate them in the switch apparatus as a definite part thereof.

Upon the commercial introduction of the multiple switchboard, which, though invented as early as 1879, did not obtain general acceptance until about 1884 or 1885, it seemed that the time for organizing these several devices into a complete and self-contained machine had arrived.

The thought underlying this type of apparatus is that the entire switchboard shall be divided into sections of suitable magnitude, and that each telephone line entering the station shall pass to every section and be furnished at each with a switch socket, so that at each section any two of the entire number of lines may be united for through communication. As practically worked out, the call receiving indicators of the whole number of lines were divided between the sections; and thus it came about that the call of a subscriber is always answered at some one section, and that switch connections in response to such call and between the calling and the wanted line are always made at the section where the call has come in and been answered.

There is no truth, however, better established than this: that each radical advance in electrical apparatus involves and paves the way for a number of subsidiary devices. And so it was here. The very fact that all of the incoming substation lines were represented by switch-sockets, and were accessible at each of a plurality of switchboards or switchboard sections, rendered further invention imperative. It became absolutely necessary to provide some means whereby the operator at any one of the sections could quickly find out for herself whether a line called for, was or was not "busy." Accordingly, such means were devised. Without a "busy test" the multiple switchboard would be little better than a theory. Provided with a busy test system it becomes the practical basis of continued subsequent improvement.

Nearly all practical "busy test" arrangements provide that the insertion of a switch-plug into any one of the switch-sockets of any line at any switchboard shall bring about some electrical change which can be tested for, and detected at all of the other switch-sockets of the same line. If found to be present, the operator infers that such line is busy, but if when tested for, such change be not manifested, the line is free and may be switched.

Scores of "busy test" arrangements have been proposed; but few are really practical. In that which was associated with the earlier multiple switchboards, the socket frames of every line were represented on the face of the board by a metal ring surrounding the plug-hole; and all the metal rings of all of the sockets of each line were permanently united to one another by a wire running along at the back. The shank of the switch-plug was also wholly of metal, and when inserted in the socket of any line at any board it acted to establish a conductive connection

between the telephone line proper, and the conductor uniting the metal rings, thus grounding the latter, since the telephone line was grounded at the sub-station. A small battery was included in circuit with the operator's telephone at each section-operator's position, and keys were provided whereby the telephone might be looped into any one of the switch-cords, a number of which were placed at each position. Thus,to test at any section for the ground, cross, or other abnormal condition, which would indicate that a wanted line was engaged at some other section, it was merely necessary to touch the tip of the switch-plug to the metal ring (hence termed the " test ring ") of the socket, which at such section represented the line called for. Should the wanted line be busy, a portion of the current of the small battery would pass by way of the test ring and the tip of the plug through the operator's receiver and produce a clicking sound therein; but if the

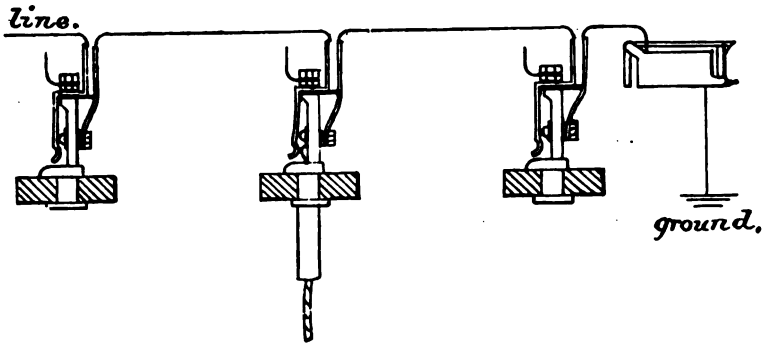


FIG. 1.

line when thus tried were disengaged, no such sound would be heard. In the multiple switchboard of that period, the jacks or sockets of the lines at each section were arranged in panels over the front of the board; the call devices were annunciators arranged in banks below these panels; the switch-cords with plugs at each end hung from a kind of gallows frame above; and on a keyboard in front of the operator were keys associated with the several switch-cords respectively, for directing the call current over any line switched to any particular cord, and for similarly connecting the operator's telephones in the circuit of any cord to answer calls, and to talk with either subscriber. The disconnecting annunciators, one for each switch-cord, were mounted on a single row at each section. The circuits were of the single wire type with earth return; the switch-sockets of the several lines—one for each line at each section—each had a spring and point

contact, and these contacts as indicated in Fig. 1, were all in series in the line.

As arranged for the switchboard of that period, the operators' telephones common to all cords of the section, were connected in an earth branch of the cord conductor; and the disconnecting annunciators, one for each switch-cord, were each connected directly in the circuit of its own cord. Fig. 2 indicates this arrangement.

Switchboards of this general type were installed for several years—the first one employed in New York being placed in a central office in John Street—and in general were clear improvements over everything preceding them; and among other features of advantage they greatly increased celerity in operation.

The disclosure, under operative conditions, of faults, weaknesses and opportunities for improvement was, however, inevit-

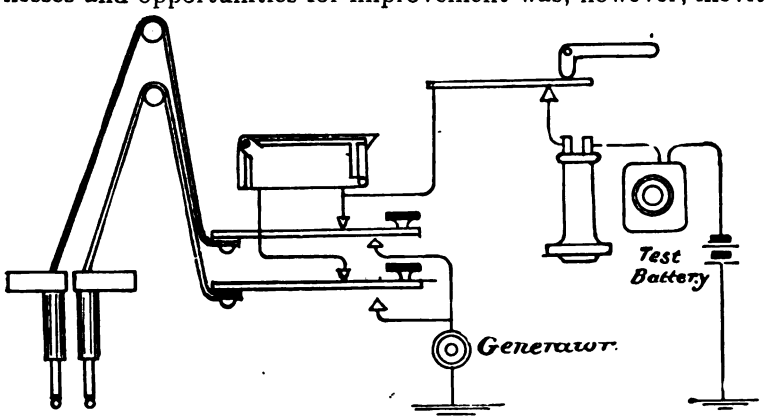


FIG. 2.

able, where the engineers of both manufacturer and user were constantly on the watch. It was very soon observed that the manipulation of switch-cords hanging from a point above, was a strain upon the operators, besides being in other respects inconvenient; and soon their position was changed, and the plugs were made to rest with the calling and listening keys on the keyboard, the cords hanging below with a weight for each, to keep it taut, and for its automatic retraction. Then it was noted that the speed of operation was restricted because on the receipt of a call signal, the jack of the line, the call of which was to be answered, had to be found in the panel where it and adjacent numbers were placed; and to the avoidance of this defect, the next improvement was directed. There was provided for each line at the section where its calls were answered, an additional

switch-socket to be used for the answering plug of a pair, and in responding to calls only. This was termed the " answering jack," and was placed close to the call signal of its own line. Switch connections were greatly facilitated by this expedient because whenever a call was received the operator was not required to take thought, but might at once plug into the answering jack which was close by.

After some four or five years' use of grounded circuit multiple switchboards it became evident that the time for the inductively neutral metallic circuit had arrived. One multiple board, the largest thus far constructed, had been set up and wired for grounded circuits; but so clearly was it seen that to proceed further in that direction would be a mistake, that this board was

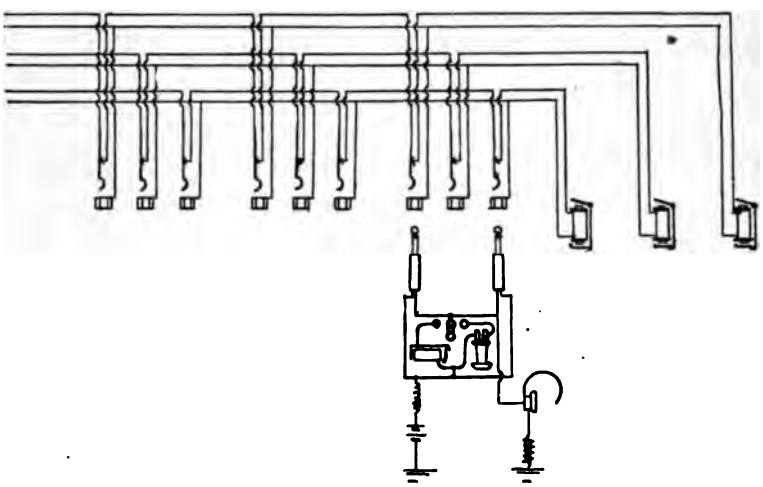


FIG. 3.

not put into operation until it had been completely re-wired for metallic circuits. This advance was a radical one, and followed the introduction of underground wires, almost as a matter of course. The series mode of arranging the spring-jack contacts was at this time retained, these being in one conductor, while the other main conductor was connected by parallel branches to the test rings of the circuit at the several sections respectively.

In this arrangement which is shown in Fig. 3, the call annunciator was connected on the answering-jack section between the two main conductors, the normal circuit through it being opened by the separation of the jack contacts when the switch-plug was inserted. This step in the onward progress of the switchboard carried one or two auxiliary improvements in its train. The

operators' telephones and clearing out annunciators were no longer connected alternatively in series in the cord conductors, but after a few tentative arrangements, were bridged between the cord strands, controlled, however, as before, by their several keys; but when thus placed, it became necessary to wind the disconnecting annunciator with many turns, and thereby give it a high resistance and impedance; as otherwise the voice currents from either of two circuits switched together, tended to be shunted through the bridged signal device.

The switchboard had now become a really good and homogeneous machine, well adapted to satisfy the conditions and requirements of its own day; and here for awhile its development seemed to be stayed. Yet it was soon seen that there was abundant scope for further advance. New switchboards became old, and old ones older. Others though still new were employed in the soft-coal consuming cities of the middle west. In all of these cases, and more particularly in those last-named, the series-connected jacks developed high-contact resistance which materially weakened the loudness and clearness of conversation transmitted through the circuits concerned; and as the number of lines connected increased with marvellous rapidity, it was found that the switch-sockets occupied too much space on the face of the board, so that a considerable reduction in size soon became imperative, in order that the requisite number of switch-sockets might be crowded, without detriment to operative efficiency, into a given space.

The subsequent development of the telephone switchboard depended upon the outcome of three apparently parallel and independent but really coördinate and gradually convergent lines of investigation, which were all about this time under consideration.

These investigations were directed towards:—

(*a*) The further improvement of the switchboard apparatus proper, by abolishing the serially-connected jack contacts, which as indicated, were a prolific cause of imperfect service; and by substituting some form of construction wherein each subscriber's line, when switched to another, would have a clear, continuous and highly conductive path through the switchboard for the voice currents; together with such other changes as each progressive advance might render necessary.

(*b*) To do away, if possible, with the multitudinous transmitter batteries of the sub-station and operating room, and to substitute

for them a common central source of transmitter current; for if this could be done, there would not only be effected a great reduction in the number of cells required, but such as were required might be kept at all times under the eye of skilled employees.

(*c*) To arrange if possible for the gradual displacement of the sub-station call-generator, and the necessity for its operation in the transmission of incoming call signals; to provide that call and disconnect signals should be automatically transmitted by the simple acts of taking the receiver from the hook switch, and restoring it thereto; and to devise suitable appliances at the central station for the appropriate display of these signals.

These several directions of prospective advance seem superficially to have little necessary community with each other, but the closer they are viewed, the more apparent will it appear that the realization of all would inevitably involve the complete re-organization of the switchboard; and that the efforts thus far devoted to the subject must be regarded henceforth as having resulted mainly in the determination of the principles which should be followed; and of what features were and were not desirable in an ideal switchboard. This was a well advanced position; and constituted a definitive foundation on which the completely organized super-structure of an efficient modern switchboard might be successfully reared.

Considering first the direct improvement of the switchboard as a means for the rapid interconnection and satisfactory through operation of lines, it is sufficient to say with respect to the diminution in the size of the parts, that experience and practice had by this time enabled manufacturers to make spring-jack and other mechanism very small. The main problem was clearly the elimination of the serial spring-jack contacts. But how? Naturally, by arranging the switch-socket contact members at each section in parallel branches from both of the main conductors of their respective lines. But here was a difficulty: the serial spring-jack contacts were not by any means purposeless. The manifestation of incoming calls involved a subscriber's circuit, closed at the central office end, and an annunciator or similar call device connected in it; and the main purpose of the separable contacts in each jack was to ensure that while the spring member of such contacts which was on the lineward side should engage the inserted plug, the same should also be lifted by the plug tip from the fixed or insulated pin contact, thus opening the circuit at that

particular socket, and cutting off all that portion of the circuit inwardly; that is to say, the original terminal including all following switch-sockets, together with the annunciator. Herein lay the difficulty; for if the insertion of the plug merely made contact with two branch springs, and did not sever the main conductors, how should the original terminal and annunciator be cut off?

It is of interest to note that the connection of multiple board jacks in parallel was not at this time a new idea. Indeed, the multiple board as first devised was on this plan; but as then suggested, the difficulty outlined did not occur, since the board in question was intended for use in association with circuits over which incoming calls were not sent (there being a special call circuit), which circuits therefore did not have a central station annunciator, and might be, and were left normally open.

Every telephone engineer had known almost from the inception of the art, that electromagnets indiscriminately placed in series in a telephone circuit strongly opposed the passage of the rapidly changing voice currents, making reproduction of speech weak and indistinct; and by this time Oliver Heaviside had coined the word "impedance."

But if we take electromagnets out of the main conductors, they will of course no longer oppose the passage of the voice currents in their legitimate circuit, and if we then connect the magnets in bridge between the mains, we no longer need to disconnect them when we unite one line with another, because they still retain the impedance, which can be increased to any desirable extent, and because we can then make that impedance useful to prevent wastage of the voice currents through the bridges thus constituted. The disconnecting annunciator had, in fact, as we have already seen, been so connected; and on party lines there were many high impedance "bridging bells," so-called, also in parallel between the mains; which were employed without bringing about any perceptible depreciation of the transmitted speech. So then the first solution came to several minds at once. Why disconnect the calling annunciator at all? Why not disregard it, and leave it connected with the line while the circuit is switched, depending upon its impedance to prevent the short-circuiting of the currents through the annunciator branches thus left intact. This was done, but it became necessary as in the prior case of the disconnecting annunciator, to wind the magnets with many turns, and generally to make them of high impedance. There was, however, nothing objectionable in so

constructing them, because the higher the impedance, the less chance there was for the voice currents to be shunted that way.

Fig. 4 shows in diagram the talking circuit as thus formed between two sub-stations; the circuits of such sub-stations being switched together under these conditions. In this figure L and L^2 represent circuits extending from sub-stations S and S^2 respectively, to a central station C, and there provided with permanently connected call annunciators A and A^2. They are supposed to be united for conversation by the switch-cord conductors *c*, between which the disconnecting annunciator *d* is bridged. So connected, the line annunciators are obviously bridged also, and thus the through circuit has at the central station three bridges, each containing an electromagnet. Here, then, arises another difficulty. The wanted station must be called by the central station operator after the switch-plug is inserted in the proper line jack; and since the annunciator of the wanted line is not cut off, it will respond unless means are taken to prevent. Moreover, since it may be and probably is at another

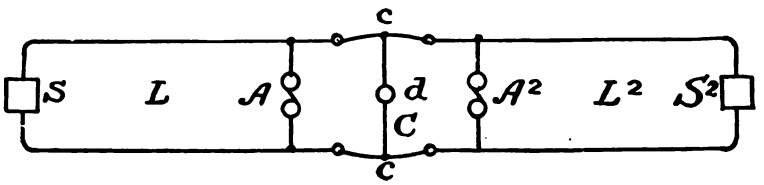


FIG. 4.

section of the board, its operation will doubtless be regarded as a call by the operator there, who of course will try to answer the supposed call. Again, when the conversation is over, and the sub-stations S and S^2 ring off, the line annunciators A and A^2 are again likely to respond, one of them in any event being probably at another section of the board, so that this also will be taken as an incoming call. A number of propositions looking to the avoidance of such false signals were proposed, but the most promising plan for the latter contingency was so to arrange the switch-plugs and sockets, that the insertion of the plug might close a local circuit containing an electromagnet, which magnet would when excited by the closure of its circuit, act to hold the armature of the annunciator in its normal position so that the annunciator could not operate and display its signal, even though a current should pass through its actuating magnet. This device, which is indicated by Fig. 5, worked in fact so satisfactorily that it not only prevented the undesired operation of the

annunciator, but also acted to re-set the same, when the signal had been given, pursuant to an original call; so that a drop fallen to display such signal did not need to be manually replaced, but was automatically restored as soon as a plug was inserted to answer the call.

In Figure 5, *a* represents the actuating and *d* the retaining magnet; *h* and *h'* are switch-sockets having line contact springs *i* and *i'*, and contact rings *k k'* one behind the other, arranged to be conductively united on the insertion of the plug and through the metal shank thereof. The tip *l* of the plug makes

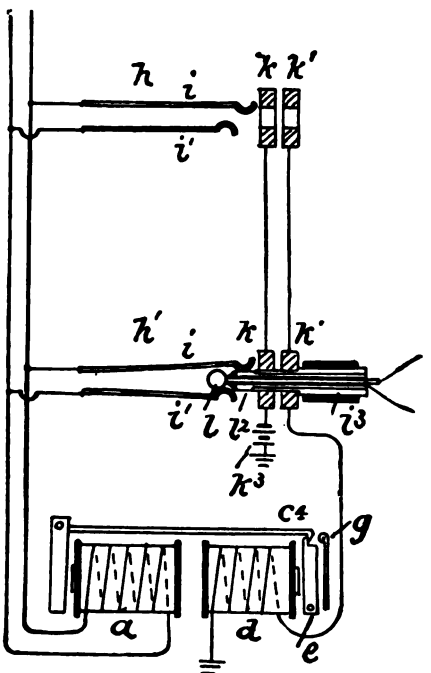


FIG. 5.

contact with the shorter line spring *i'*, the ring contact l^2 of the plug with the longer spring *i*, and the shank or sleeve l^3 with the two rings *k k'*. The inner rings *k* of each line are normally connected to each other, and to the grounded battery k^3; and the outer rings to each other, and to one end of the winding of the retaining magnet *d*, the other end of which is connected to ground.

A pivoted shutter of iron *e* is normally held by the armature catch c^4, and when released effects the display of the signal plate *g*. When the plug is inserted, the current of the battery k^3

excites the actuating magnet *d*, and this magnet attracts the iron shutter *e*, preventing the display of the signal, and withdrawing the said signal if it has been displayed.

In sending outgoing calls over the wanted line, a satisfactory expedient to prevent the operation of the annunciator of the line wanted, was so to connect the actuating and retaining magnets, that while incoming call currents passed through the actuating magnet only, outgoing call currents were passed through both actuating and retaining magnets.

So many adverse electrical influences were now abroad, by reason of the numerous heavy current systems which had been installed, that the " busy test " arrangement already described was no longer serviceable. Charges and stray currents on the line due to such influences tended to produce false busy signals. Accordingly, a form of " busy test " circuit never crossed or conductively associated with the line conductors, but altogether local was substituted. The insertion of the plug for the purpose of switching one line to another, was made to close one of two gaps in the local test circuit which was in part formed of the several test-rings of each line and the conductor uniting them; and also acted to connect a battery thereto, thus raising the potential of all the test rings of the line at all sections. The other pole of the battery was connected through the operator's telephone to the tips of all of the calling or companion plugs. Thus, when the tip of such a second plug was applied at any section to the test ring of the wanted line, the occurrence or non-occurrence of a click in the instrument, enabled one to readily infer the engaged or disengaged condition of the said wanted line. As thus modified, a number of switchboards were installed, and the type of apparatus became known as the " branch terminal " switchboard. The talking currents, had through this board a clear conductive path not liable to be impaired by the presence of jack contacts or other abnormal resistance; and in fact without any contacts other than those made at the actual switching points. Thus far, then, a desirable advance had been attained, and the branch terminal or parallel connection switch-socket arrangement has remained in use until the present time.

The branch terminal switchboard at first brought commercially to the front, did not provide for the other two desiderata which have been indicated. Yet these were not very far behind. It was more important to provide a central source for sub-station

transmitter supply common to all or a great number of lines, than it was to provide a similar arrangement for calls and other signals. But it seemed likely that if either could be practically arranged, the other might also be provided for by some modification of or addition to the same means; and in the end, thus it has turned out.

After much consideration and trials, both experimental and commercial, of many plans, the " how " of an efficient central and common battery system for telephone circuits, and the central and sub-station transmitters, together with a system of incoming call signals and supervisory signals was as a whole devised, and decided upon. In it, the same central office source of current may be employed for both signals and transmitters. The branch terminal mode of switch-socket connection was retained, each socket being composed of a frame-piece with a test ring in front, and two or more internal contact springs. At each section are the call devices, and the answering jack for the lines which are to be answered there, and a switch-socket for all lines entering the office; there being also a sufficiency of switch-cords, each with a switch-plug at each end.

The sub-station circuits were then arranged to be, while at rest, conductively closed at the central station through a battery and call device, and conductively open at the sub-station; but it was necessary to provide some kind of an operative circuit for the polarized sub-station bell, as otherwise calls from the central station could not be received; and the plan which seemed most promising, and which has been generally adopted, is to place a condenser between the severed ends of the two line conductors and in series with the bell magnet. By this expedient while the circuit is open at the sub-station for a steady current, it is practically closed for the passage of the alternating ringing currents of the central station generator, to which the bell is adapted to respond. There is also the ordinary hook-switch which serves as a support for the receiving telephone when not being used; and as long as the receiver remains in place on the hook, the foregoing conditions continue; but as soon as the receiver is lifted from the hook, the metallic circuit is closed through the sub-station telephones and the current of the central battery being thus enabled to flow, causes the operation at the central station of the call signal relay.

A small glow lamp serves as the line or call signal, possessing the great merit of being prompt and self-acting both in display

and withdrawal; and in practice is placed in a short local circuit controlled by the call signal relay, which has its magnet connected in the main line, and is responsive to the initial operation of the sub-station hook-switch.

Fig. 6 indicates the arrangement, which as regards the initial

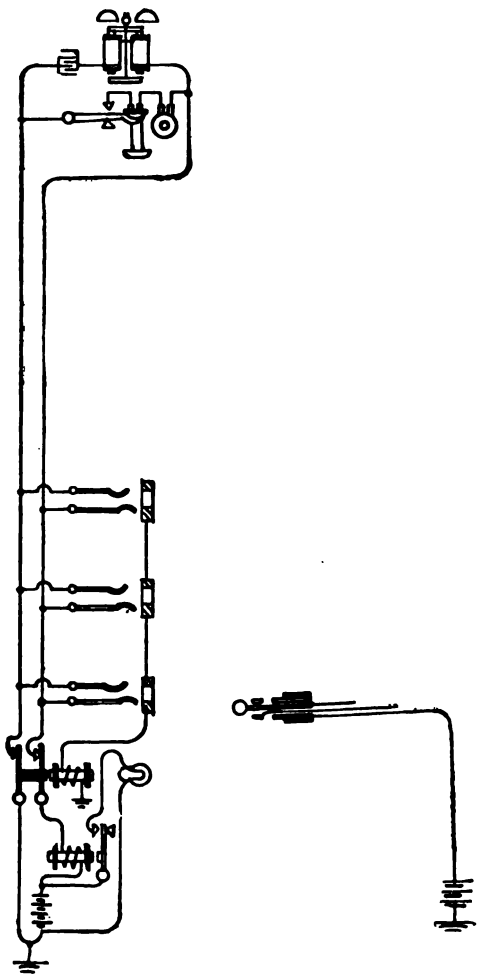


FIG. 6.

call signal was now complete; and also illustrates the devices now to be described.

The constantly connected annunciators of the branch terminal board were thus superseded by a relay and a lamp, and the appliances formerly employed to maintain the quiescence of such

annunciator were now made, instead, to operate a cut-off relay by means of which the lamp-operating relay might be cut away or disconnected, and the lamp signal thereby withdrawn, as soon as the call was answered by inserting the switch-plug. This cut-off relay has two resting contacts through which the two conductors of the main circuit respectively pass, in such manner that on the excitement of the relay and the consequent attraction of its armatures, the contacts are parted and the continuation of the line, including the call relay and the normal battery connection is cut off. The cut-off relay itself is in a local switchboard circuit controlled by, and leading through contact pieces of the switch-plug and socket. The switch-socket for this purpose has interior contact springs for both main conductors, thus leaving its frame-piece or test-ring at liberty for the local circuit; and the several test rings of each line are united by a fixed conductor extending from all of them to one terminal of the cut-off relay. The plug also has three insulated contact pieces adapted to register with the two line springs and the test ring of the socket; the cord conductor extending between each pair of plugs comprising two main line strands which extend from plug to plug, and a local circuit strand for each plug. A battery has one of its poles connected with the plug local circuit conductor and the other to the remaining relay terminal, so that when the plug is placed in the socket of any line, the cut-off relay circuit is closed, and the relay operates to disconnect the line terminal and relay. At the same time the potential of all of the united test rings of the line thus switched is raised to furnish appropriate conditions for the " busy test."

But this is not all. Supervisory signals are regarded as being necessary. These, also, are lamps, and two such are provided for each switch-cord, and associated with the two plugs respectively, being placed in the cord section of the local or cut-off relay circuit. Thus placed, they are, of course, non-operative except when the plug is in its socket; but the plug being thus inserted, their function is to afford an indication to the operator of the condition of things at the sub-station. They can only be displayed when the hook-switch at the sub-station is in its lower or normal position; that is to say, the position in which it is maintained while the receiver hangs on the hook. When in answer to a call the operator inserts the answering plug in the socket of a given line, the associated lamp does not light, because the sub-station receiver has already been taken from

the switch to give the order. But when the companion plug is placed in the socket of the wanted line, the lamp signal of that plug does light, because the receiver at the wanted sub-station is not removed from the hook; it thus follows that when this receiver is taken up in response to the call, the light is at once withdrawn. Again, when the conversation is over, the replacement of either or both sub-station receivers will once more illuminate the corresponding lamps to serve as a disconnecting signal. Or if either party desire at once a connection with some other line, the lamps may be made to flash several times in succession, by oscillating the hook switch. It must be apparent that such a system of supervisory signals is both ingenious and scientific. Its essential and underlying principle is that the supervisory signal of each plug is controlled in part by the plug and socket switch contacts of the local circuit wherein it is connected, and in part by the hook switch at the sub-station of the line to which the switch-socket belongs; and further, that the working of the signals is dependent in the first instance upon which of these two switch devices was first operated. Thus, in the case of a call being answered by the insertion of the switch-plug, the signal is not displayed because the corresponding hook switch has previously been operated; but in the case of a sub-station to be called, the supervisory signal is displayed because the plug and jack switch is the first to be operated, the hook switch in this case remaining unchanged until after the call is sent.

To enable the hook switch to control the signal, a low resistance relay is placed in the main circuit conductors of each plug, which relay being thus connected in the main line, is responsive to the closing and opening thereof as the hook switch is moved in one direction or the other.

The sketch Fig. 7 illustrates this arrangement, and shows that the relay in question does not act directly upon the local circuit of the lamp to open and close the same. This cannot be allowed because the same local circuit serves also for the operation of the cut-off relay and "busy test." It acts, however, by controlling a shunt round the lamp signal, closing the said shunt and preventing the display of the light when the main circuit is closed, and current consequently flows through the relay; and opening the shunt to permit the display of the lighted lamp when the receiver at the sub-station is replaced, causing the hook switch to open the main circuit so that current to excite the relay no longer flows.

In the figure, L L^2 are the sub-station circuits extending between the sub-stations s s^2 and the central station c, and adapted to be switched together for conversation at the latter. The switch-cord *c* has the battery B bridged between its main conductors, and has local circuit conductors for each plug, forming in association with the fixed conductor which unites the test rings, the local circuit; R R are the cut-off relays, R^2 R^2 the supervisory relays, *m m* the supervisory lamp signals and *h h* their controlling shunts.

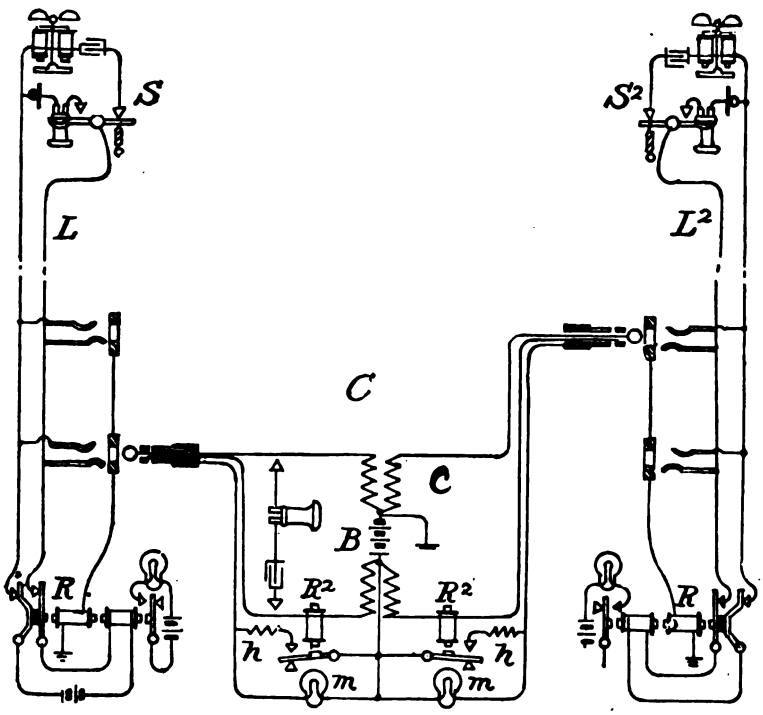


FIG. 7.

The battery which develops the current for the main line to excite the relay, is, as shown, preferably bridged between the two main circuit cord conductors, which respectively unite the tip and forward sleeve contacts of the two plugs, and so connected, divides the cord circuit into two well-defined sections looping from each plug. The same battery provided with an earth connection at one pole, may serve also to furnish current in the local circuit to illuminate the lamp signal, and indeed also for the operation of the cut-off relay and busy test appliances; the

several circuits being properly proportioned to the battery power and to one another by suitable resistances.

Another improvement tending to increased promptness of service in responding both to " call " and " disconnect " signals, is the " pilot lamp." This is an auxiliary luminous signal which may be advantageously associated with both of the foregoing classes of regular signal. It complements the regular signals much in the same way that a bell in a hotel or domestic annunciator system is made common to and complementary to the several individual drops. This pilot lamp is thus common to the signals of a group of call signals, or to a group of the supervisory switch-cord signals, and it is adapted to light whenever any of the regular signals with which it is associated is displayed. It may be placed in a conspicuous position on the front of the switchboard, so as to be readily seen by the monitor or chief operator, and its protracted display is an indication that some signal of the group to which it belongs is being neglected or disregarded; or at any rate, that some signal of such group, thus far has not been attended to. It is by reason of this function that the term " pilot lamp " has colloquially been applied to the device; although I do not say that the term is eminently appropriate. The pilot lamp like the others is connected in a local circuit and controlled by a relay, which may conveniently be placed in the circuit of the main conductor through which current is supplied to the branch lamp circuits of the group. This can readily be arranged in several ways without producing such an undue drop of potential in the branch lamp circuits as will adversely affect the regular lamp signals.

When the battery is bridged as has been described, it is properly connected for use also as the source of transmitter supply; and as has been suggested, may be and is so employed in connection, both with the transmitters of the several operators and those of the sub-stations. An important condition of success in the employment of a single battery for a large number of transmitters, is that its internal resistance shall be so low relatively to that of the circuits supplied, that the operation of any transmitter will not cause any material variation of potential at the battery terminals. When this condition is properly complied with, there will not be any interference between the circuits of the several transmitters; and such compliance is best attained by the employment of storage batteries. To further reduce the internal resistance of the battery and the chance of

interference, a plurality of banks of cells, each bank having a sufficient electromotive force for the work—say 24 volts—may be connected in parallel with each other.

But another condition equally essential in the operation of the sub-station transmitters of an exchange from a common battery, is that by means of the switchboard devices and in their normal operation, it shall be possible at any time to disestablish this universal state of reciprocal neutrality or non-interference as regards any two circuits, and so to segregate or set aside any pair or any number of pairs of circuits united for through communication, that the component circuits of such pair or pairs may freely communicate each with the other, but shall not disturb, or be disturbed by, any other circuits connected with the battery.

One plan of operation meeting this condition, which to a certain extent has been used, is to introduce a considerable impedance into the conductors connecting the main circuit strands of the switch-cord and thereby the main conductors of the two

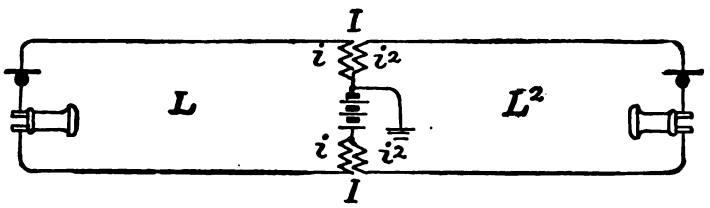


FIG. 8.

circuits concerned, with the pole or poles of the battery; and to establish a short-circuit, preferably containing a condenser, between the corresponding conductors of the two component circuits, and round the impedance. The steady current of the battery finds no further difficulty in flowing through the impedance devices than that due to simple resistance, and thus readily passes over the line in either direction to the sub-station transmitters, but cannot pass the condensers; while the voice currents developed by the action of the transmitters upon this steady current being in a state of constant and rapid fluctuation, are prevented from short-circuiting themselves through the battery bridge by the interposed impedance coils, but pass with great facility round these coils and through the path which includes the condenser to the distant station.

Fig. 8, however, illustrates an alternative plan which thus far has found more general acceptance. It consists in associating the two united sub-station circuits L L^2 and the common battery

B bridged at the central station between their main conductors, with an induction coil I of the type often styled repeating coils, wherein the two windings i i^2 have a like number of turns and like resistances. The two windings, as is clearly shown in the figure, are connected in the component circuits respectively, so that the circuits are in inductive relation with one another. Both windings are centrally divided, and the bridged battery unites the halves of both on one side to those on the other side of the circuit Each component circuit is thus supplied separately with battery current for the transmitter of its sub-station through its own winding of the induction coil; and each is alternately the transmitting and receiving circuit. The voice currents developed by each transmitter circulate in the transmitting component circuit only, but acting through the induction coil they develop substantially identical voice currents in the receiving circuit also, which passing through the same, operate the distant receiver. This arrangement well complies with the second condition of success. It divides the circuit up into two sections, having no conductive connection, and thus tends to minimize the possible effect of a fault which may exist in either; and it reduces the adverse effects which otherwise would be very noticeable when the two lines connected differ considerably in length.

In Fig. 9 is illustrated the application of this plan for central and common transmitter battery operation to the switchboard apparatus; and furthermore, represents in diagram the sub-station and switchboard connections of two circuits, showing how the same central source of current may be employed in connection with call signals, circuit control and speech transmission.

I may in conclusion briefly advert to a minor improvement which in some installations has been added with a view to further relieving the operator of the time-consuming duty of following up sub-operations. This is a device combined with the ringing key, which acts after the key has been manipulated, to lock it in the ringing position with the call generator connected to line for a definite and supposedly sufficient period of time, or until the attendant at the station called, responds by taking the receiver from the hook. One way of arranging such a device is to provide a spring latch which when the key is depressed engages a shoulder on the key spindle; to mount the spring upon an armature; and to associate with each key an electromagnet to act upon this

armature, the same being wound with but few turns of coarse wire, and connected in the key branch of the generator circuit. The key having been pressed, is thus held in operation, because the current of the generator through the circuit (which, before the

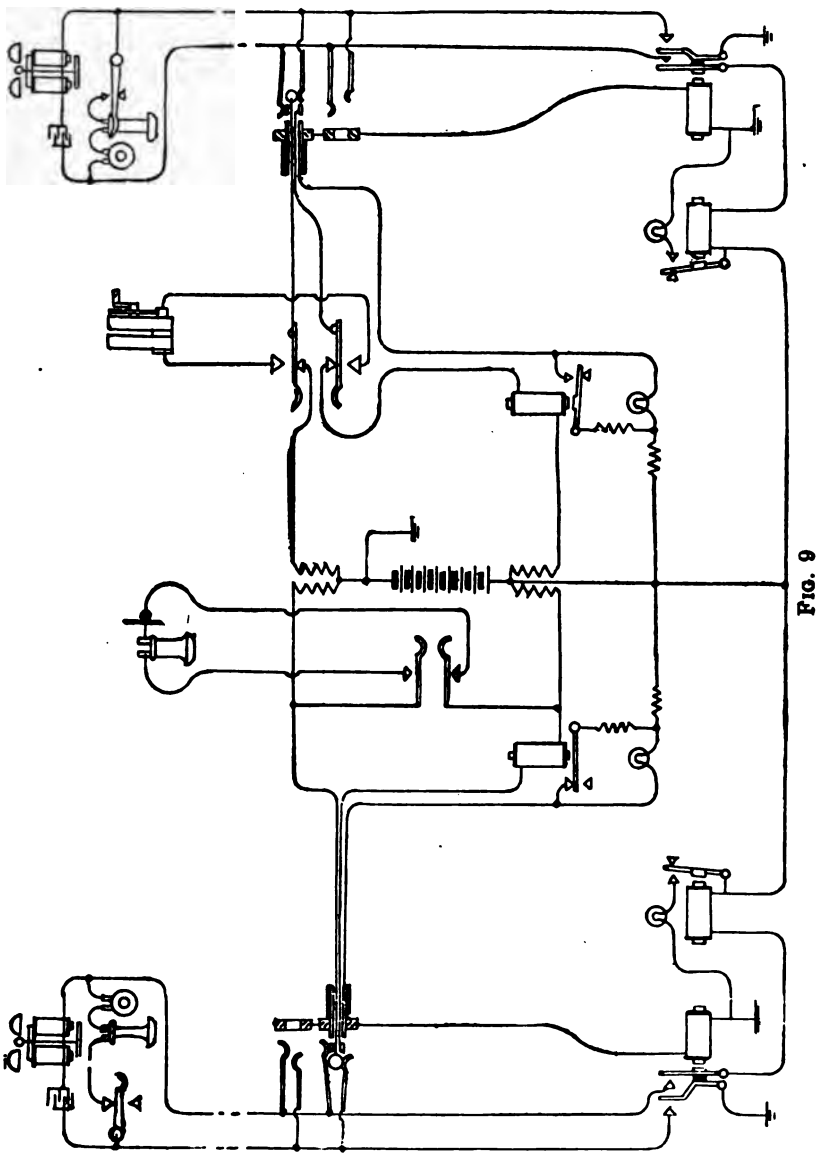


FIG. 9

removal of the receiver from the hook at the sub-station is, as we have seen, kept conductively open by the inclusion therein of a condenser), does not excite the releasing magnets. But as soon

as the call is responded to by the removal of the receiver from the hook, the circuit is conductively closed; and the generator current now steady and strong, is sufficient to excite the magnet, which attracting the armature, acts to release the key; so that the call current over the line is cut off. Such auxiliary devices, however, and others which have been suggested and which are intended to bring the operators' telephones into connection with a calling line as soon as the plug is inserted, and to disconnect them by an electromagnetic switch after the lapse of a definite period of time, or when the companion plug is inserted, or when the call current is sent to the second line, present themselves to my mind, not as essentials of the switchboard apparatus, but as refinements of the lily painting or gold gilding order; which may be employed or not, and which do not alter the general character of the finished machine or effectuate any materially modified result.

There are, furthermore, certain concomitant appliances that have grown up round the switchboard as do suburbs round a city, and which should at least receive mention. These embrace mainly the power room apparatus for charging the universal storage batteries, and for the generation of alternating currents for outgoing calls; protective devices of several coöperative types interposed between the cable heads and the switchboard to arrest and guard against the effects of various harmful intrusive currents; the main distributing frame, an iron open-work structure with interior channels through which a multitude of insulated connecting wires are led, and having binding screw terminals of cable and switchboard conductors on its two sides respectively, between which such connecting wires extend to unite any pair of line conductors to any desired pair of switchboard conductors, and at which any circuit can readily be opened or otherwise altered for testing purposes; and the intermediate distributing board placed between the main distributing frame and the switchboard proper, where all main wires are represented and can be cross-connected, and at which to distribute the business equitably between the operators, any line while retaining its multiple switch-sockets can readily be connected or re-connected with any desired answering jack and line signal, and thereby be transferred in a few minutes from any switchboard section to any other, as the fluctuating character of the work may require.

While these appliances which in every large and well-appointed

central telephone station are now uniformly provided as accessories of the switchboard, cannot within the reasonable limits of this paper be discussed in detail, they are of course to be kept in mind in planning and preparing specifications for the central station apparatus generally and the switchboard in particular; and their proportionment, design and relation to the switchboard, with which they are to be associated, are matters which in each installation require the most careful and exhaustive consideration.

There is no great invention which has more thoroughly revolutionized business methods than the speaking telephone. The exceeding value of time is better appreciated now, than at any previous period in the world's history; and it is universally recognized that a business man's time is a business man's best asset Wherever the telephone is employed—and it may truly now be said that " there is no speech or language where their voice is not heard," and wherever the telephone exchange has obtained a footing, there at once is a valuable economy of this most valuable possession attained.

It is, however, obvious that to realize this conservation and economization of time to the fullest extent, the possibilities of usefulness inherent in the telephone itself must be competently seconded by a central station switchboard through which all of the several operations and sub-operations requisite for the connection and disconnection of lines, can be carried out with accuracy and celerity. The Standard Relay Switchboard—as the organization of apparatus and circuits whose development I have traced has been entitled—is such an instrumentality; and by it, notwithstanding the marvellous increase of late years in the number of lines entering large central stations, and in the number of calls received and connections made in pursuance of such calls, the speed and efficiency of operation has been not only well maintained, but has exhibited marked improvement.

Here, then, at least for the present, we take leave of our theme. The efforts expended in producing the switchboard which for the time is standard, are amply justified by the general satisfactoriness of its work. True, its organization is complex, but so is that of every poly-functional machine; and why should we object to complexity if accompanied by corresponding efficiency; or unless it shall be proved that the same efficiency can be achieved by simpler means.

This switchboard, though not yet a perfect product of evolution, is at least a complete and successful machine; but evolution

still goes on. It may well be that the next step in its never-ceasing progress will be in the direction of simplifying the organization either in its concrete devices or in its circuit arrangements, without any sacrifice of efficiency.

A paper presented at the 172nd Meeting of the American Institute of Electrical Engineers, at New York, January 23, 1903.

AN AUTOMATIC TELEPHONE OPERATOR.

BY WILLIAM J. HAMMER.

A description of an automatic telephone exchange operator, power driven, which performs the functions of switching, signalling, line-clearing, etc., of the human operator, and by exactly similar means. Also a comparison of the salient features of the manual and automatic systems.

For a considerable period of time the public mind has been steadily educated up to a high appreciation of, and great confidence in automatic time, energy, and money saving appliances. In the telephone field the subject of automatic telephone exchanges has been one which has attracted a great deal of attention ever since the original work in this direction of Messrs. M. D. and T. A. Connolly and T. J. McTighe, whose system the writer had the pleasure of examining as long ago as 1881, at the first electrical exhibition held in Paris.

The above system has been the basis of very many of the patents which have since been taken out on automatic telephone exchanges; and it is my privilege to-night to present for your consideration a radical departure in automatic exchanges which embodies a new principle of which it is the pioneer exponent. It is a most meritorious and ingenious piece of apparatus, and is termed the "mechanical operator," in contra-distinction to all other types of automatic exchanges, as it is the only invention which does the work of switching in a telephone exchange in exactly the same manner as by the human operator, and by exactly similar means. It is a light machine, and occupies comparatively little space. It is driven by power, and moves mechanically the equivalents of the ordinary plugs and cords in the usual switchboard, connecting the subscribers' terminals together when desired, signaling both parties, and disconnecting the same automatically when parties have finished speaking: and accomplishing this without necessitating any departures from the general arrangement of circuits met with in standard prac-

tice; and doing away with all but a fraction of the relays, magnets, electrical contacts and connections essential in all other systems, both manual and automatic.

The multiple system of telephone exchanges has now reached a very high degree of perfection; and it has become more and more costly; and it is well understood that as the number of subscribers connected to any manual or automatic exchange increases, the operating and maintenance expenses increase in far greater proportion than the number of subscribers, because of the increase in the number of multiples.

There is an urgent demand to-day for a system which will *very* materially cut down these *very heavy* expenses and cut off the *very heavy* outlay now necessary for operator's salaries.

Before entering into a description of the apparatus itself, it will perhaps be as well to consider just what the functions are which the human operator fulfils in connecting and disconnecting subscribers, and in what way the mechanical operator duplicates these functions; and I will, therefore, place them side by side:

Cycle of Operations.

The Automatic System.	Manual System.
1. The subscriber sets his sender to the number wanted, and winds it; this requires the turning of the discs and moving the lever, his responsibility ending there.	1. The subscriber takes the receiver off its hook.
	1*a*. Operator notes "pilot" light signal and individual signal light.
2. The exchange drops his (the subscriber's) terminal shuttle, which starts his sender going.	2. The operator places an answering plug in his jack upon seeing his signal displayed.
	3. Operator raises the listening key cam, which depresses the key, thus enabling her to communicate with the subscriber.
3. The sender sends a signal into the exchange selector, thereby establishing *one* of a hundred local circuits.	4. She asks "number" (this operation has no parallel in the automatic exchange, as the starting of sender is a natural consequence of the dropping of shuttle).
	5. The subscriber gives the number wanted.
4. The exchange drops shuttle of subscriber wanted.	6. The operator repeats the number to prevent error.
	7. Operator must select "jack" wanted.
5. The motive power at exchange lifts both shuttles into an idle bus bar. (This operation has no parallel in manual working).	8. Operator makes a busy test by tapping with tip of her plug

6. The ringing device rings bells of both subscribers.

7. The subscriber on hearing signal takes off his receiver. (This operation not in manual practice, as receiver there is off already).

the collar of the multiple jack of the line wanted.

9. The operator plugs the multiple jack of subscriber wanted.

10. Operator presses ringing key, thereby ringing up subscriber wanted.

11. Operator restores the listening key, cutting herself out.

12. Operator notes that subscriber's signal lamp goes out.

Next, conversation begins.

Upon its Termination.

8. Subscriber hangs up receiver.

9. Clearing-out magnets drop both shuttles back to rest.

13. Subscriber hangs up receiver.

14. Two keyboard signals light.

15. Operator removes both plugs of the pair from jacks.

This is the entire series of operations gone through in a "successful switch." Should, however, a busy line be called, then the following happens.

BUSY TEST.

THE AUTOMATIC SYSTEM.

1, 2, 3, same as above.

4. Operator attempts to drop called shuttle, but it is out of the way, and a special circuit is opened.

4*a*. Shuttle is for a moment hung up, but then clears out again.

(No further operations follow, as subscriber waits for bell, before taking down receiver).

MANUAL SYSTEM.

1, 2, 3, same as above.

4. Operator in multiple board taps the collar of the multiple jack of the line wanted, and she receives a series of "clicks" known as the busy test.

5. Operator tells calling party, line is busy.

6. Subscriber hangs up receiver.

7. Operator removes answering plug from calling subscriber's jack.

It will be noted from above that the number of operations necessary varies, and favors considerably the mechanical operating system, those requiring the subscriber's attention are less in the automatic, and he need not wait for the operator to question "number," and after receiving the same, repeating to prevent error and saves that time as well as the time often lost in getting the operator to understand the correct number etc.

Comparison of Apparatus Forming Salient Features of Both Systems.

The Automatic System.	Manual System.
1. Subscriber's instrument.	Same.
2. Sender.	Not in Manual.
3. Subscriber's line.	Same.
4. Protective devices, lightning arresters, heat coils, etc.	Same.
5. Subscriber's terminal carriage with contact springs and connecting rod.	This is represented in a manual exchange by subscriber's line jack.
6. Individual magnet.	This is equivalent in office to subscriber's drop or lamp signal and its operating relay, cut-off relay, also puts line lamp out by cutting out line relay.
Above comprises the first group of exchange apparatus, and there are as many above items, as there are subscribers.	Same.
Automatic.	**Manual.**
Group 2.	
1. Bus bars.	Cords and Plugs.
2. Shuttle locks.	.....
3. Clearing-out magnets.	Clearing-out drops or supervision signals.
The apparatus in this group is present in a number equal to 1/10th of the number of subscribers.	Same.
Automatic.	**Manual.**
Group 3.	
1. Battery and leads therefrom, or dynamo.	Same.
2. Operating power.	These two items are represented by the operator, in a manual exchange.
3. Operating mechanism proper.	
The apparatus in this group is provided once only per section of 100 lines.	Same.

Description of the Automatic System and its Operation.

It is difficult to give a complete technical description of this system without recourse to many numbered drawings, diagrams, photographs, etc.; and those who are specially interested in this subject will find it of great service to witness the actual operation of the system itself, which may be seen at the present time in New York City.

This system comprises two separate devices: first, A "mechanical telephone operator," situated at the telephone exchange,

the original form of this being shown in Fig. 1; secondly, A " sender " or signaling apparatus, as shown in Fig. 2.

THE " SENDER."

Let us first consider the " sender " and its functions. It is preferably placed near each subscriber's telephone, and by its means each and every subscriber is enabled independently to control the mechanical operator at the central exchange. There is no mechanical connection of any kind between the subscriber's instruments and the " sender;" and it can be attached without cutting the circuit; it being only necessary to connect it in parallel across the existing line and to ground. The ground connection is only made for the switching act, when the instruments are idle, and during conversation they are free from ground.

The subscriber's " sender " or calling apparatus consists of a small metal box containing a set of disks, numbered on the periphery from 0 to 9—one comprising the units and the other the tens; and in the case of higher numbers being employed, additional disks are attached—three disks would give numbers up to 1,000; four disks would give numbers up to 10,000 and five disks up to 250,000. The number of the subscriber to be called is displayed in a line across the " sender " face, and a series of impulses corresponding to this number are sent over the line to the exchange by means of a clockwork started by turning the calling lever projecting from the front of the " sender." This lever upon being turned upwards winds the spring of the clockwork, it then returns to its first position, where it is locked, thus preventing further interference until the call has been sent and properly received at the central exchange. When the " sender " starts the varying series of impulses which are sent over both legs of the metallic circuit simultaneously, the ground (which has been automatically thrown on) is used for a return circuit. The " sender " also contains a magnet whose armature normally retains the clockwork until the magnet is energized by current from the exchange. As in the case of a messenger call or fire alarm box, the calling lever must be turned to its full extent to send a signal, and after this has been done, the protective devices in the " sender," as already stated, keep all the essential parts of the " sender " locked during the dispatch of the signal. When the switch is completed at the exchange, the subscriber, as well as the party whom he has called, receives a bell signal. There are four of these signals given to called subscribers, cover-

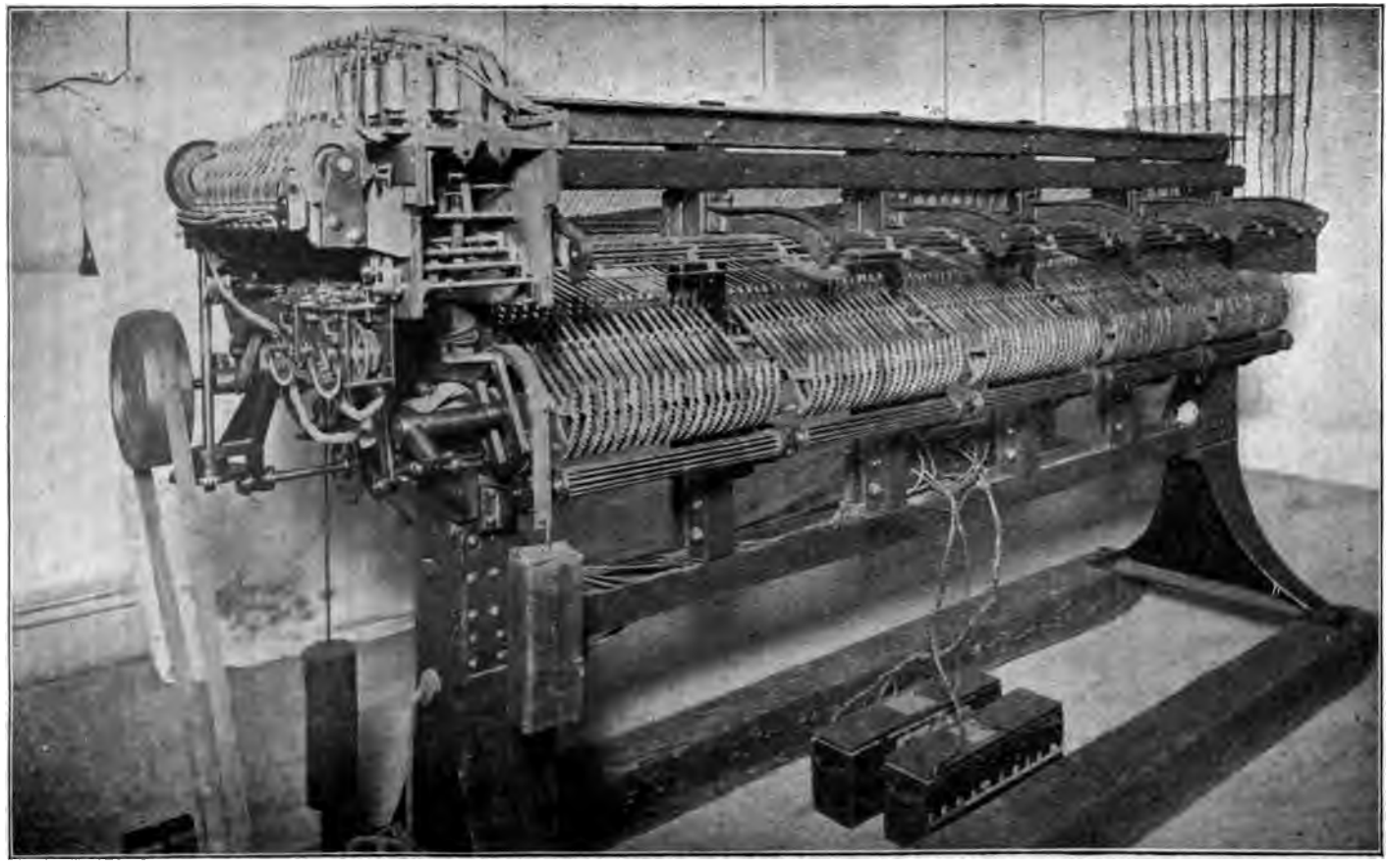


FIG. 1.—The Automatic Exchange Operator (Original form).

ing a period of 30 seconds time; this period giving the called subscriber time to reach his telephone. As soon as he has taken off the receiver the signals cease and conversation begins.

THE MECHANICAL TELEPHONE OPERATOR.

We will now consider the operator (shown in Fig. 1), and its functions:

All subscribers' circuits are normally free from ground and as already stated, the subscriber's calling device or "sender" is normally open, both as to ground and metallic circuit. In Fig. 3 is shown a diagram of the circuits.

Each subscriber's line terminates in one place only at the exchange—this being a feature not possessed by other automatic systems—each subscriber's line, consisting of two wires, is connected at the exchange to two parallel rods on the mechanical operator.

These rods are insulated from the rest of the machine, each pair supporting a carriage, mounted so as to slide on these rods.

This carriage holds the subscriber's terminal springs, which are insulated from each other, but each spring makes an electrical contact with one of the two rods.

The springs on the carriage are adapted to slide by, or at some particular point to make contact with one of a series of bars laid in a grill at right angles to and above the carriage rods.

All of the rods or bars employed in the machine are of such dimensions as to have practically no resistance, and the conducting bars and loop circuits connected with them containing impedance coils, and a source of electrical energy, such as a storage battery, and constitute the equivalent of the cord circuits of the manual exchange, and in their functions correspond identically therewith.

While the number of subscriber's terminal carriages is equal to the number of subscriber's lines, the number of cord circuits, or pairs of parallel bars necessary, need not be more than 10 per cent. of this number, this figure having been found safe in manual exchange practice. There are instances in which boards have had to be equipped with twelve and even sixteen cord circuits per 100 lines, but the average present multiple practice is from seven to ten.

It is never found that all subscribers wish to talk at one and the same time.

When the subscriber's line terminal switch or carriage at the

FIG. 2.—Subscriber's Instrument and Sender.

exchange is at a position of rest, one of the subscriber's line terminal springs makes a contact with the ground spring, which is connected to one of a circle of commutator pins. These pins are swept over by a revolving brush attached to the shaft of what is termed the " busy wheel " and which is normally in rotation. There are as many pins on the commutator as there are subscribers, and the revolving brush establishes a connection between a ground spring (subscriber's line) and a battery, operating magnet and ground.

The " busy wheel " to which the commutator brush is attached is driven by a friction clutch from a power device operated preferably by an electric motor, and is arranged to be stopped by a pawl and ratchet controlled by the operating magnet termed the " starting magnet," which initially controls the entire switching operation of the exchange. The energizing of the "starting magnet" stops the "busy wheel" and starts the operating gear, which passes through its complete cycle, after which the " busy wheel " is again started, continuing to revolve until the " starting magnet " is again energized.

A second magnet termed the " restarting " magnet is employed to start the master shaft going again; in order that the carriage-moving or cord-circuit operating device of the called subscriber may be thrown into gear.

These two " starting " and " restarting " magnets operate in conjunction with the subscriber's " sender " through the medium of a controlling contact apparatus and selector.

The commutator above referred to consists of two sets of circularly disposed contact pins, the number of the pins in each circle representing the number of subscribers.

There are also two metal contact rings, one of which is solid and the other divided into ten equal segments.

The rotating trailer arm attached to the " busy wheel " shaft sweeps over these contacts. The contact pins of one circle are each connected to a separate ground terminal spring; and one of the contact rings is connected in circuit with the " starting magnet," a battery and ground connection. The purpose of the *contact device* is to prevent any other subscriber from throwing the " starting magnet " into operation while switching is going on, the circuit in this " starting magnet " being always opened, save when the "master shaft" is at its point of rest. Each subscriber's line is brought into connection with the ground—once in each revolution, by the revolving contact arm.

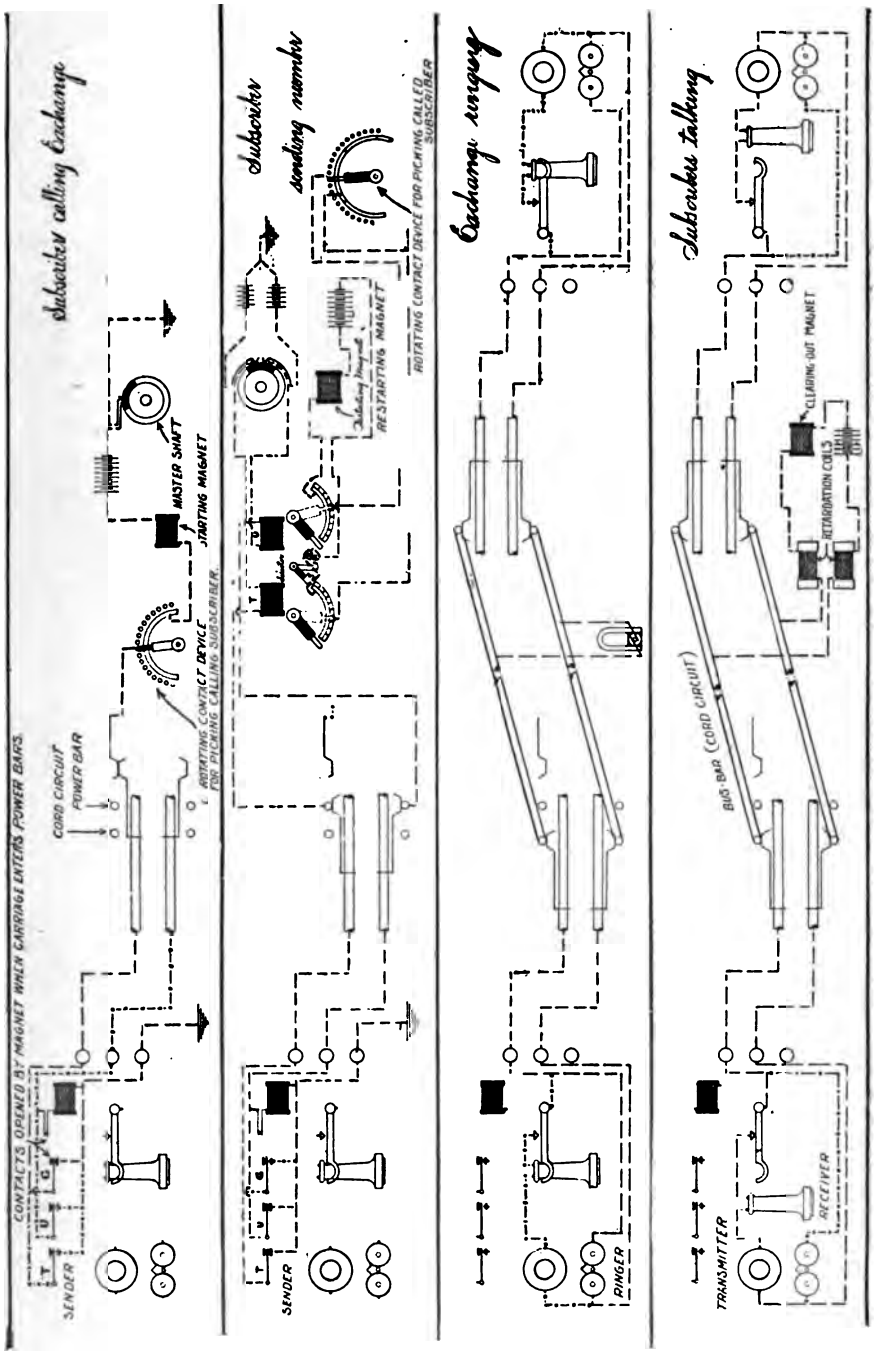


FIG 3.—Diagrams of Circuits.

All apparatus shown in solid lines. Wiring shown in dotted and broken lines. Broken lines show circuits closed. Dotted lines show circuits which are open.

The " busy wheel " which has been referred to, consists of a shaft extending through the entire length of the " mechanical operator," which carries mounted upon it and disposed around it in the form of a helix of a single turn, a series of resilient fingers of thin sheet steel, their number corresponding to the number of subscribers.

When the "busy wheel," which is normally running, has been stopped by an impulse sent through the " starting magnet," one of the steel fingers, which is always the one in a perpendicular position, remains resting against the latch holding that particular subscriber's terminal carriage. Next the power mechanism acting through a clutch and cam shoves forward a light shaft termed a " rack," which is studded with pins corresponding to the number of steel fingers and latches, and which runs parallel with the axle of the " busy wheel." As this " rack " moves longitudinally, the

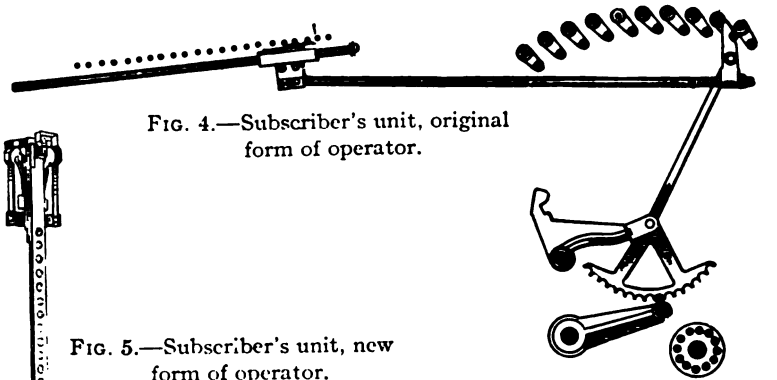


FIG. 4.—Subscriber's unit, original form of operator.

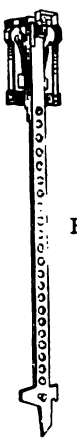


FIG. 5.—Subscriber's unit, new form of operator.

upright steel finger is bent over by a rack pin tripping the latch and thus releasing that subscriber's rod and shuttle, which drop into contact with a long lantern pinion; this pinion then rotates through an arc dependent upon the number of subscriber's lines busy at that time. Instantly a lever engages the two subscriber's shuttles, lifting them up so that their hook heads engage a shuttle detent. There are as many of these detents as there are talking circuits., *i.e.*, one-tenth the number of subscribers (in this machine the number being ten).

A circuit is now established between the springs of the subscriber's carriage and the grid bars representing the cord circuit terminals.

The magneto generator is now thrown on the circuit, ringing the bells of both calling and called subscribers. The length of this

signal may be varied to suit requirements and is controlled by a timing device. In the meantime the power mechanism has been automatically thrown out of operation and the " busy wheel " again rotates until another call is sent in.

When the subscriber takes his receiver off the hook a " clearing-out " magnet prevents the switch from clearing out; but when both receivers are hung up, the " clearing-out " magnet becomes de-energized, and its armature causes the shuttles connected to return to their position of rest.

Indirect or Trunking System.

Up to the present time we have considered the original type of the operator, as illustrated herein, and applicable to small exchanges up to 100 subscribers and employing the so-called direct connection, requiring a single machine accessible periodically to all subscribers. There have recently been made very important changes in the general design of the operator and its mechanical details, without altering the general principles under which the system operates. These changes have greatly increased the speed of making connections, cutting the time down to 3½ or 4 seconds for a trunked connection. The new operator is considerably smaller and lighter in weight, more compact, more " get-at-able," and much cheaper in cost of construction. In this machine also is embodied the indirect or trunking system, applicable to exchanges from 100 up to 250,000 or more subscribers, uniting all, if required, into a single system without sacrificing the plug and cord principle, and without multiplying the subscriber's contacts, as in all other systems, and finally, making it entirely practicable to sub-divide the lines into groups of 100, thus keeping the dimensions of the connecting machines within moderate limits.

The act of connecting subscribers, consists of three functions, each represented by an independent section of the operator. In the order in which these devices are thrown into use in establishing a connection, they are termed the " originator," the " pilot," and the " terminator."

The "originator" performs the office of establishing a connection of the calling subscriber's line with the " A " trunk. These " A " trunks are conductors connecting the " originator " and " pilot," and their number represents the maximum number of subscribers which would at any time be simultaneously using the section. It is well to note here that these " A " trunks always

have their beginning and ending in the " originator " and " pilot" of one and the same unit of 100. In this initial act of the " originator," no selective operation controlled from the subscriber's station takes place; but the " A " trunks which are already in use are made inaccessible to subsequent calls, the " originator " always selecting a free and idle " A " trunk. The end of the first free " A " trunk is connected in the " pilot," with a receiver or selector, which immediately upon the establishing of the connection between the " A " trunk and the subscriber's line receives a group-signal referred to later; and thereupon selects a " B " trunk corresponding to the signal received. Immediately the mechanism of the " pilot " connects the " A " trunk and the " B " trunk, at the same time breaking the connection between the " A " trunk and the selector, and putting the selector in connection with the next idle " A " trunk—the " B " trunks referred to connecting the " pilot " and the " terminator."

The ends of all of the " B " trunks, coming from one and the same section of 100, are distributed over all the " terminators " of the exchange, rendering it possible by the aid of one of these " B " trunks to establish a connection between the " pilot " and any one of the " terminators." Here again, as many " B " trunks are provided for each " terminator," as are necessitated by the maximum demand for simultaneous conversations between the two groups.

In the " terminator " the first idle " B " trunk is again connected with a selector which, upon the connection of the " B " trunk with the " A " trunk, receives the number signal. Immediately the connecting machinery establishes a contact between the " B " trunks and the contact element in the " terminator," representing the number of the subscriber wanted, which number has been transmitted to it.

Each subscriber, it will be understood, belongs to a certain group of 100, and in this group he possesses a contact element both in the " originator " and " terminator," these being connected to his line in parallel, protective devices being provided by means of which, as soon as the subscriber making a call has caused this particular contact-element in the " originator " to leave its normal position, his corresponding element in the " terminator " becomes inaccessible to other calls, and should any be made they would result in a " busy " signal.

The ringing up of subscribers, conversation and the clearing-out is done in precisely the same manner as in the direct method of connection previously described.

CERTAIN OF THE CONSTRUCTION DETAILS.

The "sender" is identical with that already described and employed upon the original type of the operator. The mechanism at the exchange, as I have already stated, embodies the "originator" "pilot," and "terminator."

The "Originator."—This consists of the switchboard, the movement and clearing-out device."

The switchboard consists of 100 perpendicular tracks, upon which 100 shuttles independently ride up and down. The track rails are insulated from one another, and connect in pairs to the subscribers' lines. The shuttles consist of two metallic parts in contact with the rails, but insulated from each other, each carrying a contact spring, by means of which they may be brought into contact with the "A" trunks.

The "A" trunks in the "originator" consist of horizontal metallic rods placed at right angles to the tracks, enabling each one of the shuttles to be brought into metallic contact with any one of the trunk rods. They are arranged in two parallel vertical planes, one in front of and the other behind the shuttle tracks. The ends of these rods are metallically connected to similarly disposed rods in the "pilot." It is self-evident, therefore, that when a subscriber's line is connected to an "A" trunk this is practically an extension of this line into the "pilot."

Each shuttle is provided with an actuating rod, by means of which it may be operated by motive power. In the position of rest, this rod is supported by a trip which, on being actuated by a magnet, allows the shuttle to drop. This magnet receives the current as soon as the subscriber winds his sender—this act resulting in putting the shuttle into its initial working position. The moment the shuttle reaches this position a projection upon its actuating rod protrudes into the path of a helical projection mounted on a continuously rotating drum, so that the shuttle is carried into its second working position.

The actuating rod cannot be moved further in this direction, owing to a stop in its path; consequently, the drum which is driven by friction is brought to a standstill. The moment this happens, the main mechanism is started, actuating the working beam which extends across the entire switchboard. A projection on this beam seizes the shuttle rod and lifts it into the so-called speaking position, *i.e.*, that in which its springs make contact with the first idle "A" trunk.

On completing its stroke, the working beam returns to rest.

This stops the connector movement, and the drum driven by friction is again started. The shuttle in the meantime remains in the position in which it was placed. In this position the shuttle actuating-rod rests upon a clearing-out bar, which prevents it from dropping back. There are as many of these clearing out bars as there are " A " trunks. These have a lateral movement, and when moved they release any shuttles which happen to be suspended from them. How this is accomplished will be referred to later.

At the next call the entire operation is repeated, save that the busy " A " trunk is " jumped " and the next one occupied, and so on.

The " Pilot."—In this we find again the switchboard movement, clearing-out apparatus, and in addition a group signal selector.

The construction of the switchboard is identical with that of the " originator," save that the drum is eliminated, and shuttle actuating-rods pass directly from position of rest into second working position.

The " A " trunks from the " originator " again terminate in rods, being provided with a branch circuit to the selector. These branch circuits are normally opened, and are opened during conversation over the trunks; being closed automatically part of the time during the switching act and during the transmission of the group signal.

The shuttles are here connected to rods in the various " terminators," so that the particular shuttle which is selected decides into which groups the subscriber's line will be extended.

The electrical stop motion in the subscriber's sender permits only partial running down of the " sender," but sufficient to transmit that part of the signal corresponding to the first two figures of the number desired. This is the group signal; and after its transmission, the selector in the " pilot " causes the particular shuttle to drop into working position. But immediately the shuttle reaches such a position, the actuating movement is started, and, as already described, establishes connection between the shuttle and that one of the " A " trunks over which the signal came. Thus, the subscriber's line is continued into that one " terminator " in which the subscriber's line which is desired is located; and it now remains to show how the particular line wanted is selected out of the hundred lines in that group. This will be shown in the description of the " terminator."

It is essential to mention here that the circuit, thus far built up, has in it a clearing-out magnet and parallel with that a non-inductive resistance. The province of the former being to maintain the established connection until the conversation is finished. A clearing-out in the "pilot" effects a clearing-out in the "originator."

The "Terminator."—Here we find again the switchboard actuating mechanism, clearing-out mechanism, signal selector, and the ringing apparatus.

The construction of the switchboard is identical with the ones already described, the 100 shuttles forming the terminals of the 100 lines of the group, and the metallic ends of the terminals of the "B" trunk which meet here coming from the different "pilots" where they had their beginning in shuttles.

All these rods have open branch circuits to the selector; but one of these branches at a time is closed temporarily the moment the "pilot" establishes connection between an "A" trunk, and a "B" trunk. Now, the sender is again released, and the transmission is effected. When the signal has been transmitted, the selector at the "terminator" effects the dropping of that one shuttle which carries the number wanted; and if its corresponding shuttle in the "originator" is idle, it is thus connected with a "B" trunk; thereby establishing connection between two subscribers.

In the other case the "busy" signal is given to the "originator," and the connection so far established is taken down.

Next, the ringing machinery is actuated, causing the signal at the called subscriber's instrument—this signal being repeated usually four times. It may be any number.

Should the subscriber not answer, the connection is cleared out, again.

As soon as the subscriber answers, the ringing mechanism is cut out and the talking battery is thrown in, so that no time is lost. On completion of the conversation the clearing-out magnet with its parallel resistance clears the line.

The comparison as to simplicity of operation in trunked calls is evidently still more in favor of this automatic system than even that shown in local calls—as the following comparison of operations necessary—shows.

AUTOMATIC.	MANUAL.
1. Subscriber sets "sender" and winds it up.	1. Subscriber takes off receiver. 2. Subscriber's individual light at exchange lights up, above pilot light.

2. Subscriber's shuttle drops.

3. Subscriber's shuttle is lifted into connection with an " A " trunk.

4. Subscriber's "sender" gives the group signal.

5. Pilot drops corresponding " B " trunk shuttle, and connects it with " A " trunk.

6 Subscriber's "sender" gives number signal.

7. Terminator drops called shuttle, or, if busy, gives busy signal, Otherwise connects shuttle with " B " trunk.

8. Terminator throws automatic key on called subscriber's line, ringing same,

9. Called subscriber and calling subscriber take off receiver.

10. Automatic key is restored, and talking battery throws on the line.

3. Operator places answering plug.

4. Operator varies listening key.

5. Operator asks number.

6. Subscriber gives number.

7. Operator repeats number.

8. Operator presses order wire key. Gets into communication with the trunk operator in the central office with which the called for subscriber is connected.

9. Operator gives number of subscriber wanted to *incoming* trunk operator at the second exchange.

10. *That* operator repeats number.

11. That operator gives number of idle trunk to be selected.

12. First operator releases order wire key.

13. First operator connects idle trunk to her cord circuit, thereby establishing connection between trunk and calling subscriber.

14. Second operator tests called subscriber's line, for busy using the trunk plug.

15. If idle, operator plugs multiple jack with trunk plug.

16. Second operator presses automatic key.

17. Automatic key rings subscriber.

18. Called subscriber takes off receiver, thereby restoring automatic key.

Next, conversation begins.

Upon its termination:

11. Calling subscriber hangs up.

Clearing-out magnet drops his connection in originator and pilot.

13. Called subscriber hangs up.

14. Clearing-out magnet drops balance of connection.

19. Calling subscriber hangs up receiver.

20. Supervising lamp at first operator's position lights up.

21. Called subscriber hangs up.

22. Second supervising lamp lights up.

23. First operator pulls out plugs.

24. Disconnect lamps at second operator's position light up.

25. Second operator pulls out trunk plug from multiple jack.

Special Classes of Service.

In modern telephone central exchange practice certain special classes of services are demanded; and these the automatic system already described will take care of in an eminently satisfactory manner; also adapting itself to the present central energy or common battery system, in a manner impossible with any other automatic exchange.

This system eliminates totally the large force of manual exchange operators, and only in the "toll service" the human operator is for the present essential.

I will consider in turn the manner in which the system would take care of each of these special classes of service.

"*Toll Connection.*"—A special number on the sender will be designated as "toll operator's" number at the exchange, she being called up just as any subscriber is. The operator then asks one what number is wished, and what the number of the calling party is, stating that she will call you when she gets the party you desire. This acts also as a check upon the service, and prevents a dishonest party giving another subscriber's number.

"*Restricted Service.*"—As in manual exchange practice, the toll operator would have a complete list of parties receiving such service, and decline to give any outsider long distance connection until he has been properly identified.

"*Appointment Calls,*"—As in manual exchange practice, these would be made through the toll clerk, who is communicated with through the operator's number on the sender.

"*Automatic Pay Station Service.*"—Such service would require a metering device, perferably a nickel-in-the-slot attachment. The nickel being returned in case no service is rendered. Or a metering device such as a cyclometer, responding to the action of the receiving hook, but *only* when circuits are established or service actually rendered. At the central exchange, a metering device would be operated in conjunction with the "busy test" apparatus, enabling the operator to check off such service, as in present manual exchange practice.

"*Inquiry Calls,*" "*Information Bureau,*" "*Complaints*" *and* "*Transmitted Messages.*"—In addition to the operators in the modern manual exchanges, information men, trouble men, etc. are employed to answer inquiries, attend to complaints, and transmit messages. The four classes above mentioned would be attended to in precisely the same manner.

"*Party Lines.*"—A four-party line selective ringing service can easily be given.

ADVANTAGES OF THIS AUTOMATIC SYSTEM OVER OTHERS.

The following points of advantage which are claimed for this automatic system have been investigated by me; and I deem them well worthy of consideration of every telephone engineer.

It is applicable to an exchange of any size.

It is applicable to the present standard central energy system.

It is applicable to any commercial telephone, and to the present arrangements of circuits met with in standard practice.

The total elimination of the multiple principle from this system makes it possible to sub-divide the exchange into several separate local exchanges together forming a large city system, and this without destroying the principle of unity in the system and without decreasing the speed of connection. In this manner a great economy in line construction and maintenance is effected.

It employs the usual protective devices of lightning arresters, heat coils, etc.

It gives a prompt service, the total time taken to transmit reliably a trunked signal of four figures, is about three-fifths of a second, and the average time to secure connection is found to be from three and one-half to four seconds.

It will give a more reliable service, and with equal efficiency at all times. Unlike the human operator it is never impatient nor impertinent, and does not become fatigued or ill, and does not drop in efficiency, under stress of the rush hours.

The saving of space occupied by this exchange will be very great, as compared with the space required for a multiple manual system. I am informed that the lowest calculation for space in cities is about a thousand square feet per one thousand subscribers, giving, say, ten thousand square feet for a ten thousand line exchange, and this is a *very conservative* estimate. In contrast it is claimed that 100 machines of 100 lines each, with sufficient lane-ways between each machine both ways, of say 2 feet, and a center lane of 3 feet, would only occupy 62 by 55 feet, or in all three thousand four hundred and ten feet.

It will do away with a large corps of skilled attendants at the switchboards, eliminating one of the heaviest expenses attendant upon the telephone industry.

It will do away with a percentage of employees necessary to keep the central station cables, wires and appliances in condition, and lessen the cost of inspection and maintenance.

It is claimed that it can be installed in large and medium sized exchanges, at 30 to 40 per cent. less cost than the present multiple

exchange system, and that the contacts in say, a ten thousand exchange would be 80 to 90 per cent. less in number than in a multiple exchange. It is possible to add at any time groups of 100 very easily without disturbing the existing installation, and thus increase from time to time in proportion to the demand. It would show much more nearly in a direct ratio an increase in expense of operation and fixed charges with the increase in the number of subscribers, than would be possible with the manual exchange which, as is well known, increases out of all proportion to the increase in the number of subscribers.

It will do away with employee's dressing, dining and reading rooms, clothes lockers, infirmary, matrons, etc., as well as considerable expense for ventilating plant, lighting and other sanitary arrangements necessitated by the usual crowding together of a large number of human operators in modern exchanges.

It permits of a large number of subscribers calling simultaneously, without producing confusion, the calls being stored up and brought into communication with the exchange in numerical rotation.

It requires a single piece of machinery for 100 lines, in contradistinction to the majority of automatic exchange systems, which require one machine to perform the switching for each subscriber's line.

A most important feature is, that it does away with the cords and multiple connections; and as the ground or drop connection is broken when the subscriber's carriage leaves its position of rest, a perfect balance of circuits is ensured, and the absolute isolation of each pair of communicating subscribers.

It gives a continuous trouble test, instantly throwing any line in which trouble has developed, either inside or outside the exchange, into communication with one of the lines, which may be the wire chief's. A permanent record is also made of these troubles.

It requires no batteries and no extra circuits at subscriber's stations, as in all other automatic systems.

It does not necessitate the subscriber's waiting to hear the operator ask "number ?" and repeat same to prevent error—thus saving the subscriber's time on each call.

It provides a sender which is "fool-proof," it being locked when operating, preventing further interference until signal is sent and properly received at the central exchange.

It does not require extra wiring, or even cutting of subscriber's

lines in order to install the sender; there being no mechanical connection of any kind between the subscriber's instrument and the sender; and the sender may be placed at the subscriber's telephone or at any convenient point. It is only necessary to connect it in parallel across the existing line, grounding the third binding post of the sender.

It necessitates no multiplicity of idle wires, crowding and complicating the working space, as in other exchanges, which amounts at times to 25 per cent. or more.

It requires but a single power driven pulley.

It embodies no parts operating at excessive speeds, in the original type of machine, the driving shaft being run at but 250 revolutions per minute with the operating parts driven by double back gearing at from 12 to 15 revolutions per minute.

It embodies in the mechanism of the original form, but four cams on a single shaft, each acting upon rollers; a single cam controlling all movements, with the exception of the ringing controller. In the new type of "operator," "sun and planet" gears take the place of the four cams in the original "operator."

It employs a single carriage with a connecting rod for each subscriber at central.

It provides a set of metal rods exactly corresponding to the connecting rods of the manual exchange in place of a large number of contacts constituting a multiple of all the lines in the exchange at each "selector," which is a predominant characteristic in all other automatic exchanges. It is substantially built with comparatively few wearing parts, and no telephone cords, plugs and jacks, line drops, lamps, relays, etc., to wear out; the cords being especially troublesome and expensive.

It requires but two operating batteries, no matter what the size of the exchange may be. One battery furnishes current to the switching apparatus, the other for conversation. Some automatic systems employ several batteries at the exchange, and in addition, a local battery at each subscriber's station.

It uses less current than the present multiple boards, as only one per cent. of the circuits of the exchange when idle receives any current at all, and that for but a fraction of a second. In some automatic exchange systems the current is very considerable, as compared with the maximum requirements of the exchange.

It makes and breaks every contact by power. No contact in the exchange is made or broken by means of an electro-magnet

(on the principle of a relay), not a single relay being employed on the machine.

It can coöperate with manual exchanges, and can call and be called by such exchanges.

It can be completely wired in sections at the factory, with the single exception of the " B " trunks; and at the place of installation it is only necessary to connect the " B " trunks to the " terminator," and to connect each subscriber's line once, a proceeding which is not possible in any installation employing the multiple system. It employs large contact surfaces. It handles all calls, no matter how many subscribers call at once. It possesses a perfectly balanced circuit at all times, having no multiple branches or taps. This is impossible with the manual or with automatic systems generally.

DISADVANTAGES OF THE MANUAL EXCHANGE SYSTEM.

Heavy disbursement for operators' salaries.

Important conversations between subscribers may be listened to by the operator and others at the exchange; and although this is not to be feared to any considerable extent in large exchanges, it is nevertheless a fact that the absolute privacy ensured by the automatic exchange system is highly appreciated by the telephone subscriber. At each call considerable of the subscriber's time is consumed in giving the operator the number desired, and having her repeat the same to prevent mistakes; and frequently the subscriber has to repeat the number several times by reason of his or her indistinct speaking, or standing too far from or too close to the transmitter; or by reason of disturbances on the line, or interference of other sounds in the proximity of the telephone. There may also be interference due to other subscribers being cut in on the lines.

During rush hours it has been necessary at times to station behind the usual operators, special operators, who facilitate the handling of the board by pulling out the various plugs. And it is not an uncommon practice when there are troubles at the switchboard, and possibly even during the congestion of the rush hours, for the operator to report a line busy, thus staving off temporarily the calling subscribers. Circumstances have been known where subscribers have been told repeatedly that the party whom they have called was busy; and on his making inquiry at that party's office he has found that the telephone had not been used during that period.

The reason why the multiple board deteriorates faster than the

balance of the installation lies in the fact that practically everything has to be sacrificed to considerations of space. A well-known telephone authority in this country has stated that the allowance for depreciation on the switchboard should not be less than 10 per cent; and while the common battery board is doubtless much better than the magneto board, it is believed that with this mechanical operator, with its large surfaces of contact and ample mechanical margins, the depreciation would be much less.

The cost of construction where the multiple section system is employed is enormous. It is a fact well understood by experienced telephone men that, as the number of the subscribers which are connected to any exchange (whether manual or automatic), increases, the expense, both of operation and maintenance increases in far greater proportion than the increase in the number of subscribers. This is not the case, however, with this automatic system, which, as regards the central exchange expenses and construction expenses and maintenance charges, increases more nearly in a direct proportion with the increase in the number of subscribers.

The length of reach of the human operator in the manual exchange is very limited. She is generally expected to cover a section of board 30 inches each side of her. This is not the case with this mechanical operator, the range of which is practically unlimited. Furthermore, in the latter case, the machine is not delayed by connecting and disconnecting, as it can connect and disconnect at one and the same time, a function which is not possible with the human operator.

In considering the disadvantages of automatic exchange systems hitherto invented, it is readily understood why they have met with such limited application up to date, notwithstanding the realization by telephone men the world over, of the many advantages of automatic exchanges; it is because of the inherent delicacy of the various electrical and mechanical devices employed and the rapid depreciation of these devices. It is also due to their extreme complexity, especially in the multiplication in the numbers of wires, contacts, relays, magnets, etc., which increase out of all proportion with the increase in the number of subscribers. It is quite common to employ from five to seven or more magnets and relays in each switching device, and employing one to three of these switching devices in establishing the necessary connections, and utilizing these magnets and relays for performing the actual mechanical work of lifting, rotating and

switching the mechanism employed with all the disadvantages which this entails; and finally, it is by reason of the very high class of engineering talent essential in the designing and constructing of the complicated apparatus which has been employed.

It is self-evident to all electrical engineers who have had experience with electromechanical devices that it is far better to employ a well-designed mechanism performing a definite cycle of operations and driven by some source of power.

This mechanical operator has been designed and constructed upon the following lines: *i.e.*, an absolutely reliable, prompt, rapid and uniform service in telephone exchanges of any size; an embodiment of all essential features demanded by the exigencies of modern telephone practice; an elimination of the unreliable, flimsy and complex features inherent in systems heretofore presented to the public; and finally, the effecting of large economies in construction and maintenance charges.

The author of this paper believes as a result of his investigations into this system, that these claims made for it will be borne out in actual practice; and he considers it a privilege to be able to present for your consideration what he believes to be one of the most important and interesting inventions ever brought before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Discussion.

President Scott:—Mr. Thomas D. Lockwood, electrical engineer and advisory electrician of the American Telephone and Telegraph Company, will read his paper on "The Evolution of the Telephone Switchboard."

Mr. Lockwood:—It will take a good paper to stand up to the introductory remarks of President Scott. It is a number of years since I last stood in this place, but the Institute, nevertheless, is always, and always has been, with me an object of solicitude; and I shall never, I think, be perfectly satisfied with the condition of the Institute until it has an audience room of its own far more fitted to its importance and requirements than this room, good as it is, can ever be. Perhaps, as President Scott has pertinently observed, there never was a greater invention than the speaking telephone. I do not think I am ever more impressed with its far-reaching consequence (and that is never absent from my mind, although I have been nearly twenty-five years connected with the telephone business) than when I sit in an office in Chicago and talk to my home near Boston. On such occasions the mystery of it comes over me, as I fear it can over very few persons; for when I think that one small iron plate can perform, under the influence of varying magnetism, and varying currents, all of the several functions which in the human individual require the coöperative work of the lungs, the palate, the lips and the tongue, I cannot but realize how great indeed is the intellect of man and how wonderful this one of his achievements. I was much impressed at a meeting held in Washington to celebrate the institution of the patent system of the United States, when an orator observed that while he felt that he could get upon familiar terms with a dynamo at a respectful distance, and while to some extent he could appreciate the electric telegraph as being something which even he was capable of measureably understanding, when it came to the telephone he was stricken with awe, for, as he said, while we have it on the authority of the Master that none of us by taking thought can add one cubit to his stature, Alexander Graham Bell by taking thought had added not merely a cubit but hundreds of miles to the length of our tongues and ears. I, therefore, you will understand, am one of the very last men in the world to belittle the telephone; and yet, standing here, as I do this evening, I am willing to asseverate even in this distinguished company, that the telephone without the telephone exchange system would have been incomplete; and that to the inventors who have perfected the plans for the telephone exchange, aided by the brilliant engineers who have made effective these plans, almost as much honor is due in the interest of commercialism, at least, as to him who laid the foundation for them—Alexander Graham Bell.

[Mr. Lockwood then read his paper (see page 127)].

Mr. Lockwood:—I did not intend to read as much of this

paper as I have, but it is the first time I have had a chance to read it, and I grew rather interested in the paper as I went along. If its contents have been to my audience but one-tenth as luminous as they are voluminous, I shall be perfectly satisfied.

(Vice-President Dr. Samuel Sheldon in the chair.)

VICE-PRESIDENT SHELDON:—I think we have all enjoyed this extremely interesting and valuable paper by Mr. Lockwood. It is doubtful if anyone else could have written so acceptably and so authoritatively on the subject. The discussion will be opened by Mr. J. J. Carty, chief engineer of the New York Telephone Company.

MR. J. J. CARTY:—To-night we have enjoyed the rare privilege of listening to a paper from Mr. Lockwood. The subject of his discourse is one of which he is the master. Condensed with admirable precision, he has put into 27 short pages an epitome of switchboard progress of the past twenty-five years. This was twenty-five years of intense effort, of struggle and failure, and of ultimate success. Within no similar period in history has there been displayed so much energy and so much successful work in connection with any industry. Of the magnificent results of this work the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has particular reason to feel proud.

Beginning with the telephone itself—the foundation of it all—we find it is the invention of one of our own members, Prof. Bell. I regret that he is not present with us to-night. In speaking of Prof. Bell, we cannot help but think also of another distinguished member, Mr. Edison, whose work in connection with the telephone is so well known to us all. Upon the foundation work of Prof. Bell down almost to the humblest improvement which has not yet been passed upon by Mr. Lockwood, this entire development has been the work almost exclusively of the members of this INSTITUTE. Nearly all of these electrical mechanisms of which we have heard to-night are the direct product of our own members, or have been produced by those coöperating with them or under their directions. I think, therefore, that in no other branch of electrical engineering can it be said that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS is more immediately concerned. In reference to no other branch of electrical work can it be said that they have reason to feel such a just pride.

It is not only as members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, but also as Americans, that we have reason to be proud of this work. It is nowadays the fashion to talk much, especially in the daily papers, about "American industrial supremacy." With braggadocio of that sort I have no sympathy. Nevertheless, for a special reason, it is pertinent to call attention to the fact that little, if any, contribution to the results described to-night has been made by any country except America. Of course, from this I must except the foundation work which was done by the noble band of immortals headed by Faraday, which the old world has produced. As specific

workers in the telephone field I must except two names—I refer to Van Rysselberghe of Belgium, who has given to us simultaneous telegraphy and telephony, and to the Rev. Mr. Hunning of the Church of England, who gave us the granular carbon transmitter. In the form in which we received it from him it was not fitted to survive this evolution of which we have heard to-night. It remained for an American, the late Mr. Anthony White, to convert the granular carbon transmitter of Hunning into the "solid back" transmitter of to-day.

Mr. Lockwood tells us of the successes which have been attained in telephone switchboards, but he has said little, if anything, of the failures. For every one of these successes there has been a multitude of failures. Many of the ideas which have been discussed have been contributed directly by Mr. Lockwood himself. With reference to many of the improvements, he has exercised great influence, and toward all of them has acted as a sort of godfather. With respect to the failures, his relation has not been so pleasant. Toward them he must be considered as being a "Lord High Executioner." I think it is safe to say that not a single important invention in relation to the telephone has been seriously proposed for the last twenty-five years, that has not been fully considered by Mr. Lockwood, and upon which he has not reported. In my experience I have found that he has rarely allowed a bad thing to pass by him without being properly stamped, and I have never known him to turn down a good thing. I am sure that there are a multitude of inventors who would not agree with me in this statement, but it is nevertheless true.

I had intended to offer some statistics showing what results might be obtained from systems employing the apparatus which Mr. Lockwood has so well described, but time will not permit, and there are many speakers to follow. I will give one fact, however, from our statistics which is very significant as showing the degree of practical perfection which telephonic apparatus has now reached. From carefully kept records of all the troubles in connection with the 100,000 telephone stations in Manhattan, it is found that each station is out of order during the year for a period of only 1 hour and 27 minutes. That means that on the average, each station would be in good order during the entire year, except for the brief period of 1 hour and 27 minutes. These figures are taken directly from carefully kept records. They are trustworthy and accurate.

VICE-PRESIDENT SHELDON:—The discussion will be continued by Mr. F. A. Pickernell, engineer of the American Telephone and Telegraph Company.

MR. PICKERNELL:—The subject has been so well covered in the paper which Mr. Lockwood presented that there is really not much opportunity for discussion. I do want to refer to one factor, however, that has been abundantly taken care of in the modern switchboards. You all remember in the early days of

telephony very many exhibitions were given of telephonic transmission between cities over lines of considerable length. Such development was not particularly rapid in the early days, because the number of stations was small, and some of the switchboard difficulties referred to had not been fixed up. However, as the switchboard was improved and the number of stations increased, the demand for long distance service, service between the cities, increased enormously, and every part of the apparatus used in switchboards had to be designed so that it would work satisfactorily in connection with such lines. A switchboard engineer, if he designed defective apparatus, might impair the service to an extent which could not be counterbalanced by the introduction of tons of copper in the long distance circuits. Some of those electromagnets in series which Mr. Lockwood referred to might not only impair the volume of transmission, but they might also introduce sources of disturbance due to their lack of electrical balance. All these things had to be cared for in designing switchboard equipment. The effort has been made and successfully carried out to arrange the apparatus so that any particular station may be connected with any other particular station within the range of say a thousand miles. The switchboard engineers have designed their apparatus so well that from the telephone station located in this building connection can probably be had with three-quarters of a million, if not a million, other stations in various parts of the country. None of these results could have been produced or attained if the switchboard design had not been of the highest possible order. That is the one thing I care to point out in connection with the subject under discussion this evening.

VICE-PRESIDENT SHELDON:—The discussion will be continued by Mr. B. Gherardi, Jr., chief engineer of the New York & New Jersey Telephone Company.

MR. GHERARDI:—The prevailing idea of the electrical engineer just graduating from college is that in telephony there is little for the engineer to do; that at best it furnishes only a field for the electrician or the mechanician. An instrument screwed upon the wall, a pair of twisted wires connected to it and an operator with some plugs and spring jacks at the central office, is all that is required. To be sure, it is not the daily task of the telephone engineer to design ponderous machinery such as is employed at Niagara; he is not concerned in transmitting for unheard of distances currents at enormous voltages; he does not make the grosser forms of engineering his exclusive concern. But it is a grave mistake to assume that with these branches of electrical engineering he has nothing whatever to do. The paper before us clearly brings out the multitudinous functions which must be performed by the modern telephone central office and indicates the variety of agencies which the telephone engineer has called to his aid.

Let us compare for a moment some of the functions of an

electric light station with those of a telephone central office. At the electric light station a certain gross amount of current is generated. This is distributed by feeders and mains through the various streets and highways of the district to be served and connections are made for the mains to the various houses requiring current. No particular unit of current generated at the central station is intended for any particular lamp or motor connected therewith. Large copper wires constituting the mains may be tapped to feed any house. The user of the electric light may turn on or off his current at will, and is not required to coöperate in any way with the central station, or with any of the other users of the electric light system.

In the telephone central office, however, there must be distributed from the central office current destined to a particular station, and this current, as a rule, is received at the central office from some other particular station where it originates. While in both electric light and telephone systems copper conductors are used, in the electric light system common conductors of large mass are employed. The current for all customers is sent out over these common wires.

In the telephone central office, while large amounts of copper are used, the particular current intended for a given station must be sent along its own conductors and delivered to its own destination. Not only must the central office arrangement provide for this, but it must provide that this current shall be delivered in the particular form and at a particular time, both of which shall be under the control of the subscriber.

The conductors leading to the electric light station extend to a switchboard, to be sure, but the connections there made are elementary in their character. Intercommunication between conductors centered at an electric light station is not the rule. In the telephone central office any line there centering must be so constituted that it can, within a fraction of a minute, be connected to any other line in the system. In a central office of ten thousand lines there are about one hundred million possible combinations of connections, which must be provided for. But it is not only subscribers in one central office that must be thought of, but connections between subscribers in different central offices must also be considered. This must be accomplished regardless of the number of central offices in any city. Not only this, but connections between any central office in a given city and between any central office in a neighboring city, must be capable of instantaneous establishment, and with the growth of the telephone system, the number of cities and towns which must be included within the vast network of wires has become practically unlimited.

Between the electric light system employed in the city of New York and that employed in the city of Boston, there is no necessary relation, but with the telephone system this is not so. The telephone system at Boston and the telephone system at

New York must be so constructed that they will be interlocking. This is true of all large cities which enter into the problem.

While, as I have stated, telephone engineers do not concern themselves with the transmission for great distances of high voltage currents, they have to contend with a transmission problem which in point of difficulties is of a vastly serious nature. Dealing, as it does, with currents defying measurement, and almost infinitesimal in amount, the work of the telephone engineer is attended by obstacles without number. Not only must the telephone engineer design his transmission system so as to take care of the currents generated by the telephone apparatus, but he must so plan that system that it will be defended against the inductive attacks of electric light and power circuits. For his own protection, therefore, if for no other reason, he must have a working knowledge of the behavior of currents of greater degree and higher voltage.

At the central office itself we have no Niagara dynamos, but we have an aggregartion of parts which may with precision be called a multitude. These parts, as Mr. Lockwood has so well pointed out, have varied and complex functions to perform. Each part has its special function, and must be maintained in definite relation to all of the other parts in the system.

Taken altogether, the demands upon the engineer in designing a modern telephone central office are not exceeded by those made upon engineers engaged in the grosser or heavier branches of the work.

I have mentioned this point, because, from observations I have made in visiting our various colleges in search of assistants from the graduating classes, I have found that the point of view which is taken by engineering students generally at these institutions is that which I have already indicated in my previous remarks. It is for this reason that I have made these comparisons, and not with a view of " blowing the horn " of the telephone engineer.

It would, perhaps, be interesting to enumerate briefly some of the electrical engineering branches which are represented in a modern telephone exchange. Wherever it is possible to obtain service such as is given so admirably to us at New York by the Edison Company, the prime source of current employed is from the street mains of the electric light company. To these are connected a motor, sometimes of 40 horse-power, and in reserve it is customary to keep an additional motor of this kind connected to the switchboard and ready for action at all times. Each of these motors is connected to a generator of suitable horse-power, which is employed to charge a storage battery. Where a direct current source of power is not available, two and three-phase alternating current motors are often employed, these being used to run the direct current charging generators. Often no electric current of any character is available for motor driving, and frequently such as may be available cannot be relied upon, and in

such cases gas engines or other prime movers are used, either as reserve or to furnish all of the power required. This use of direct current and two and three-phase alternating currents, and of gas engines and other prime movers, brings into the problem various factors of engineering supposed to belong exclusively to other branches and to be far removed from telephone engineering.

While the storage battery at a telephone central office is not to be compared in magnitude with those such as are used in our electric light stations, yet in so far as the care required in its maintenance and the knowledge of storage battery practice is concerned, the telephone engineer must be suitably equipped. He must at all times maintain the battery in condition to perform the service required of it.

From the storage battery are run various other motor-generators, which produce both direct and alternating current at various voltages to serve the diverse uses of the system. While the magnitude of the currents employed is not great, the necessity for absolute reliability is present and requires most exact and careful attention in design, installation and maintenance.

In the modern central office, the telephone switchboard is not the only one employed. To provide for the proper switching of the various machines and the prompt supplying of new sources of current in case of break-down, a power switchboard is needed. On this switchboard there are massive bus-bars, switches, fuses, circuit breakers, starting and regulating boxes, and the measuring instruments usually supposed to be peculiar to electric light and power stations. This apparatus, which I have just enumerated constitutes a complete power plant, and in its general aspects suggests an electric light station rather than a telephone office as ordinarily conceived.

Between this power plant and the telephone switchboard proper is drawn a dead line of specially designed fuses and cut-outs. In the consideration of these fuses and cut-outs alone the telephone engineer has been obliged to study questions which to the electric light engineer have probably not even occurred. Instead of large fusible wires or magnetic cut-outs carrying heavy currents, fine, hair-like fuses are employed, and in some cases we use heat coils surrounding easily fusible metal, which melts at a predetermined point and releases a spring which operates a cut-out or sends an alarm, as the case might be.

To the telephone man, a one-half ampere fuse is one that blows when that amount of current flows; to the electric light engineer, a one-half ampere fuse is one which will carry that amount of current plus an unknown quantity for an indefinite length of time. To tell the story of the fuse question as applied to telephony would be of great interest in itself, but in this discussion it can only be alluded to.

In the switchboard itself, as has already been clearly pointed out in the paper of the evening, there abounds a multitude of

questions involving intricate circuits, the mechanical disposition of a large number of parts, and the orderly arrangement of the whole so that it may at all times be ready to answer the various demands which are made upon it at all hours of the day and night. In every switchboard there are miles of conductors and cable, thousands of incandescent lamps, hundreds of relays, transformers, keyboard apparatus and other devices, each having its special function to perform, and which must be maintained at all times in a definite relation to all of the other parts. The orderly and economical arrangement of all of this aggregation of elements is one of the problems of the telephone engineer.

It is not the electric light engineer alone who has had to do with the development of transformers. Their extended use in telephony has called for a vast deal of time and study on the part of the telephone engineer, and while the transformer problem as presented to him is vastly different from that which is presented to the electric light engineer, it is still none the less difficult, and while in the design of transformers and other electric light and power apparatus, the degree of loss which should be tolerated is oftentimes dependent upon the cost of coal, we have no such conditions in telephony, for here the amount of current generated has absolute limit, and must be conserved in all of its parts if success is to be attained. Not only is there no margin for losses of current, but in respect to frequency and the shape of the wave, the telephone engineer is held to rigid limits.

The problem of centering at one point and housing such a large number of wires as are required in a modern telephone central office is a question requiring most careful study, and involves not only electrical, but also questions of mechanical and civil engineering. To terminate these wires properly and to provide for their distribution from time to time, as the varying demands of the business require, has been the subject of a great deal of study and invention on the part of many minds.

The size and efficiency of the underground cable, depending not only upon its conductor resistance, but also upon the dielectric capacity, influences the size and number of ducts in the underground cable system. This in turn affects the size of the office district which it is economical to serve, and this, taken together with a large number of other factors, determines the size of the central office. The switchboard design depends upon the size of the offices, and this, as I have indicated, is, in a large measure, dependent upon the character of the cable it is possible to employ. Thus slight changes in cable design, apparently having no relation whatever to the central office apparatus, are often found to affect its design.

In view of the vast costs and peculiar requirements of the modern telephone switchboard, it is rarely that a building already constructed can be found well adapted for the purpose of a telephone central office of any considerable magnitude. For this reason, a specially designed building must be prepared,

and ordinary prudence requires that this building should be as nearly as possible fire-proof. The construction of the building bears such a close relation to the arrangement of the telephonic apparatus that it must be subordinate thereto. For this reason there devolves upon the telephone engineer the task in the first instance of designing the telephone central office building before the matter is turned over to the architect.

All of these things have been brought to my mind by a perusal of this most valuable paper of Mr. Lockwood's, and perhaps at the risk of being irrelevant, I have felt it worth while at least to mention them in the discussion.

VICE-PRESIDENT SHELDON:—Will Mr. E. F. Sherwood, superintendent of traffic of the New York Telephone Company, please continue the discussion.

MR. SHERWOOD:—The title of the paper of the evening is of itself sufficient to attract the favorable attention of all engaged in telephony, but coming as it does from Mr. Lockwood, whose relations to the subject are so well known to us all, it is doubly interesting. What he has to-night told us may be taken with all the weight of authority. He has rapidly sketched for our interest and information the progress of the switchboard from its imperfect beginnings to that high degree of perfection which it has attained to-day. But all of the care and thought and effort which have been applied by the ablest engineers to the design and construction of the modern switchboard would go for naught unless, after the switchboard is installed, it is operated in accordance with correct methods. These methods themselves have gone through the same harsh process of evolution which has given to us the splendid mechanism of to-day. Indeed, the relation between the method of operation and the design of switchboards is so close that there has often been controversy as to which was the more important. Into a discussion of this matter it is not now my intention to enter, but I will say that as between operating method and switchboard design there is, when rightly considered, no necessary conflict. Each must be adjusted to the other and their correct mutual relations must be established. It is a fact not without significance that between the highest type of switchboard design and the best operating methods, there is no incompatibility. Both may be found together in the same organization, each in its highest form. In fact, I am convinced that in the highest form one cannot exist without the other.

In the paper itself, as well as in the discussion, the physical features of the switchboard system have been developed at length. For my own remarks, I think it might be of interest if I should present in brief form data which will give some idea of the results which may be obtained from the relay board such as Mr. Lockwood describes. I have taken data as applying to New York, because it is with traffic of that company I am particularly familiar.

For the past eight years it has been the practice in New York

to make service tests in such a way as to show the quality of the service received by telephone subscribers. These tests show the time taken by the operator to answer subscribers' calls, the time taken to complete local and trunk connections, the time taken to disconnect after conversations are finished, the percentage of connections on which irregularities occur, etc. Records of these tests have been valuable not only as a means of showing in what respects improvements in the service might be made, but have afforded accurate information as to the improvements brought about by the installation of relay switchboards.

The first standard relay switchboard installed in New York was cut into service on November 13, 1898, and the last one, which for Manhattan Island rounded out the conversion of the entire system of local switchboards to a relay basis, was cut into service November 2, 1901. The tests of service for the year preceding the installation of the first relay switchboard in New York and for the year 1902 show the following results:

	Avg. time taken by operator to answer.	Avg. time taken to complete local connections.	Avg time taken to complete trunk connections.	Avg. time taken to disconnect.
1897	7.7	27.6	50.7	17.1
1902	3.8	23.7	30.7	2.8

The improvement made in the time of answering is chiefly due to two causes: First, unlike the arrangement of magneto equipment, the answering jacks in the relay board are immediately associated with the line lamps or calling signals, so that no time is lost by the operator in locating the answering jack corresponding with the calling signal; and second, with relay equipment subscriber's lines are promptly released after conversations are finished, and delays due to slow clearing out of previous connections do not occur as they did with magneto equipment, which required that operators should listen in and ask "are you through?" in every case before disconnecting.

The improvement in the time taken to complete connections is partly due to the use of trunk line machine ringing keys, which when set, cause the bell of the called subscriber to ring intermittently until the receiver is removed from the hook; and partly to the use of cord supervisory signals, which show whether the called subscriber has answered or not and enable the operator to give a second or a third ring when necessary, without delay.

The slowness of disconnection, with the old type magneto switchboard, to which Mr. Lockwood referred, was largely due to the failure of the subscriber to ring off in a large percentage of cases—something like 14 per cent. of the subscribers hung up their telephone without giving any signal, and the operator had to discover whether the subscriber had finished by groping around and listening on the line.

The improvement in the time of disconnection is entirely due to the use of cord supervisory signals, which immediately light when the receiver is placed on the hook, and enable the operator to

disconnect without listening in on the connection. In fact, the work of making disconnections is largely an overlapping operation, and is frequently performed simultaneously with other operations which require the use of the operator's telephone.

Further evidence that the installation of relay switchboards has improved the service is furnished by the record of written complaints from subscribers. During the year 1897, when the average number of subscriber's lines in service in Manhattan was 17,066, a daily average of 3.2 written complaints were received or one complaint a day for every 5,330 lines. During the year 1902, when the average number of subscribers' lines in service in Manhattan was 49,955, a daily average of 3.3 written complaints were received, or only one complaint a day for every 15,138 lines; or to put it another way, at the rate of one complaint for each line every 41 years.

The relay switchboards in New York have been put to the most severe test, and have stood that test in a most satisfactory manner. Since the installation of the first relay board in New York, the number of lines in Manhattan has increased from 20,740 to 53,792, and the number of stations in Manhattan has increased from 25,516 to 91,945. During this time the daily average number of calls originated by subscribers has increased from 243,590 to 549,940, and the daily average number of connections handled by each subscriber operator has been increased from 750 to 1070; and yet, with this very large increase in lines, stations and traffic, and the material increase in the number of calls handled by each operator, the relay switchboards have enabled us to make a very substantial improvement in the service.

The evolution of the telephone switchboard, which has resulted in standardizing such equipment and has permitted us to install uniform equipment throughout Manhattan Island, has made it possible to establish a school for the instruction and training of new operators; and such a school was established by the New York Telephone Company on February 1, 1902. This school is equipped with a switchboard, which on a small scale is just as complete as any switchboard in service, and is so designed that all types of calls are handled by the student operators in practice in exactly the same way that they are handled at the regular central offices.

In this school student operators are thoroughly instructed in the theory and practice of telephone operating. They attend twelve lectures given by the head of the school, and after each lecture they put in practice at the school switchboard the instructions given in the lecture. In this way they learn how to handle properly the switchboard apparatus, trunk lines, etc., and also learn by actual practice the methods of handling the various classes of traffic. The course of instructions is such that on being transferred to a regular central office, student operators are competent to handle moderately busy switchboard positions.

Before the operators' school was established, the new opera-

tors were sent to the various central offices, and were instructed by experienced operators, who devoted to them as much time as could be spared from their regular duties and permitted them to practice at the switchboard when the traffic was light. The great disadvantages of this method of training operators were that students had a great deal of time during which they were not occupied except in listening in with another operator and when they first began to handle subscribers' calls, they necessarily were not so proficient as operators who have had experience at the school switchboard.

The principal advantages of our present method of instructing new operators over the old method of training them in the various central offices are as follows:

1.—The raw student element has been entirely eliminated from the central office, thereby greatly reducing the amount of interference with the service caused by inexperienced operators.

2.—The students in being trained by expert teachers acquire a uniformity of method, which has proved to be very beneficial.

3.—The time required to develop a new operator into an expert operator has been reduced two months by the establishment of the school.

4.—The total cost of training operators in the school is less than it was when they were educated in the various central offices.

The necessity for our present method of training operators becomes apparent when it is understood that in order to fill vacancies caused by resignations and to fill positions caused by the increase in the New York Telephone Company's business, and to supply operators for subscribers who take private branch exchange switchboards, of which there are 3,300 in Manhattan, we are obliged to train upwards of 700 operators a year. It is interesting to note in this connection, that there are more than twice as many operators employed in operating private branch exchange switchboards as are engaged in the various central offices in Manhattan.

With the evolution of the telephone switchboard, as I have already pointed out, there has gone on a corresponding development in the methods of operation, or handling the " traffic," as it is nowadays called. This development is by no means limited to the mere routine to be followed by operators in working the switchboard. It has been applied to the founding of the Traffic Department, the organization immediately charged with the duty of giving at all times to the public prompt and satisfactory service. So large have some of these departments grown that, in the number of their employees, the complexity of their organization, and the importance of their work, they may be compared to the entire organization of a telephone company of years ago.

From the facts which Mr. Gherardi has so clearly brought out in his remarks, there can be no doubt that among the various branches of electrical engineering, that of the telephone engineer

deserves a high rank. In addition to the varied demands now made upon the telephone engineer, there are many others which might be mentioned. So comprehensive is the subject that there are in telephone engineering already, specialties and sub-specialties.

To deal adequately with the traffic questions and operating methods required in connection with growing systems and changing types of switchboard, there has come a demand for the telephone engineer specially skilled in these matters. In all of the large telephone companies nowadays, we have a traffic engineer, whose special duty it is to study switchboard problems in their particular relations to operating methods.

To give even a slight idea of the nature of the problems encountered in traffic departments, would require a paper devoted to that subject alone. In my remarks I simply intended to call attention to problems, the nature of which are not generally understood, and the very existence of which is probably known to but few outside of those immediately concerned.

VICE-PRESIDENT SHELDON:—The next speaker on the programme is Mr. G. C. Allen, superintendent of construction of the New York Telephone Company.

MR. ALLEN:—It was with great interest that I read the advance sheets of the able paper which Mr. Lockwood has presented to us to-night. After studying with much care the splendid presentation which he has made of an intricate subject, I have wondered why it is that I should have been asked to discuss a paper dealing so particularly with central office apparatus. But after giving some thought to the subject, I have concluded that while the central office apparatus is of controlling importance in telephone systems, that, after all, it would be of little use unless it were supplemented by adequate provision for the outside plant. It is to the design and construction of the outside plant that my work in telephony has for the past fifteen years been especially directed. The central office apparatus may be considered as the cerebral headquarters of the telephone system; it is the brains of the working plant. But as the brain, without nerves extending to all parts of the body, would be unable to perform its function, so would a telephone central office be without purpose unless there were leading from it to all parts of the district served, suitable conductors coöperating with the organization represented at the central office.

In the paper which we have before us for discussion, there has been briefly traced the history of the development of the telephone switchboard and the essential principles of the existing system, which has survived from a multitude of failures. This description is notable for its accurate brevity and for its clear and forcible statement of an involved subject. It has been ably pointed out by Mr. Gherardi that the installation of the modern telephone switchboard has drawn upon the resources of electrical engineering in practically all of its departments. I shall confine

my remarks to explaining some of the new demands which have been made upon the telephone engineer to adapt the outside plant to modern conditions and to bring it up in point of efficiency to the standard set at the central office.

With the old magneto system there was upon the lines no normal current. Under ordinary conditions, that is, when the telephone lines were not in use, no current was flowing upon the subscribers' lines. The only current which these lines had to carry was the occasional ringing current employed when signalling a subscriber, and the minute telephone current impressed upon the line during conversation. Neither of these currents imposed upon the conductor or its dielectric any substantial strain. With the common battery system, however, there is upon the line at all times an electromotive force of 24 volts and during conversation there is a current flowing, although in small amount. The strain put upon the dielectric of the conductor by such a small voltage as that employed is not in any sense to be compared with that encountered in electric light practice, but considering the large number of wires which must be placed in one cable and considering the small amount of insulating material with which it is practicable to enclose the conductors, the strain is by no means negligible and as compared with former conditions, it is most substantial. Perhaps in employing the word " strain," I am conveying an erroneous idea, but when we consider the presence of a very small voltage upon the line for a long period of time, possibilities of destructive effects in the dielectric are present to a considerable degree. For this reason, an unusual amount of care is required in the maintenance of cables connected with common battery systems. The same is true of all of the wiring in the outside circuits.

As is now well understood, paper has been universally accepted as being for telephone conductors altogether the best insulating medium to employ, both on account of its low inductive capacity, as well as on account of its high insulating qualities. But these high insulating qualities of paper are present only so long as the paper is kept free from moisture. Even small amounts of moisture, which might in chemical language be referred to as " traces " will produce a lowering of the insulation which is not allowable in the best practice. For this reason, the methods of laying and maintaining cable have become more and more rigorous as our experience with this new switchboard system has progressed. Notwithstanding this, the development of engineering practice as applied to the outside plant has kept pace with that which has been applied to the central office apparatus.

Periodical insulation tests are made and incipient faults are immediately noted and steps at once taken for their rectification. It is now a matter of every-day practice by means of electrical measurements, to locate within a few feet faults in cables, whether due to the discontinuity of the conductors or to a failure of insulation.

With the advances of central office construction and with the enormous increase in conductors in such cities as New York, has come a greater extension of underground wires. At the present time I think it may be stated without fear of contradiction that considering the total mileage of wire employed, that a larger percentage in mileage of the conductors on Manhattan Island is underground than may be found in cities elsewhere. At the present time on Manhattan Island there are installed as part of the telephone system, outside of the company's exchanges, 222,543 miles of telephone conductors. Of this vast mileage of wire, 98.08 per cent. is wholly underground. Substantially all of these wires are paper insulated and covered with lead pipes. Within these lead pipes the paper insulated wires must be hermetically sealed. Exposure to the air due to a perforation of the lead pipe, even so small as a pin head, would result in the ultimate failure of the cable. This perforation of the lead pipe is as certain to produce trouble in the underground cable as a perforation in a can containing vegetables would be attended by the decay of its contents.

To give an idea of the magnitude of the task of maintaining all of these wires in lead pipes which shall be practically hermetically sealed, I may state that the total area of the lead covering required to enclose these 222,543 miles of conductors amounts to more than fifty acres. Had it been known at the inception of the telephone that the full working out of the idea of Prof. Bell would require the maintenance of such conditions, it is safe to say that at that time, no one could have been found who would give countenance to such a fool-hardy project.

The early practice of the telephone art was to employ for its cables gutta-percha or rubber-covered wires. This was natural enough in view of the fact that telegraph men were, as Mr. Lockwood has pointed out, among the first telephonists, and in telegraph-cable practice rubber and gutta-percha, particularly as applied to submarine cables, was then and is still a well-established usage. But in telephony the peculiar effects of capacity were particularly troublesome and drove us to the use of a dielectric having a low inductive capacity. In paper we have found a material which, up to the present time, has proved to be the best to use, notwithstanding its susceptibility to the influences of moisture. The maintenance of so vast a network of paper cables as is required for such a system as that of Manhattan Island is possible only by the exercise of eternal vigilance. The last central office converted from the magneto to the standard type of switchboard was the Cortlandt street office, which was corrected a year ago. The work of establishing the new central office involved an additional story on the building, putting in a new switchboard and a rearrangement of all cables. Some of the cables had to be handled two or three times, and there were over twenty thousand to be handled and re-terminated in the new terminal room and connected to the switchboard. When the

switchboard went into service on Monday morning—we generally do work of this character on Sunday—it was found that five or six of the circuits were misplaced and that connections on ten or twelve had not been properly made. These troubles were remedied, and the rest of the subscribers did not realize a change had been made in the system. The continued extensions and re-arrangements of the plant due to growth and changes in the city, and to the establishment and re-arrangement of central offices, require a degree of attention in the employment of such a large staff of engineers, that, could it have been realized at the beginning, would have been sufficient to have dissuaded any but the rashest of men from undertaking the development of what has proved to be one of the most important adjuncts to modern civilization—the telephone exchange.

VICE-PRESIDENT SHELDON:—Mr. William J. Hammer will now present his paper entitled, "An Automatic Telephone Operator."

[Mr. Hammer then read his paper (see page 31)].

VICE-PRESIDENT SHELDON:—Mr. L. W. Stanton is on the programme to participate in the discussion, but I understand he is not present just now. The hour is so late that we will not have any further discussion, with the exception of some closing remarks by Mr. Lockwood.

MR. LOCKWOOD:—I shall not keep the gentlemen more than a very few minutes. I am in the unusual position of being able to agree with all of the discussion. I thought when I came into this room that I really knew something more about the telephone exchange business than I find is the case. I have learned as much as any man in the room from the gentlemen who followed in the discussion after the reading of my paper. There are many things with which I was, of course, familiar in a general way, but the details never had been brought to my notice in such a forcible manner as they have been this evening. Mr. Gherardi's remark about the necessity for coördinating the stations in large cities, for example, cities like New York and Boston, was highly interesting. That is a remarkable thing, but it is not a matter which is reached in a moment; and the necessity for coördination was not apparent until after the long-distance telephone had rendered commercial service and rendered it well. I also was much instructed and interested in his statement, which I perhaps may paraphrase, that the telephone engineer has to be more kinds of an electrical engineer than perhaps any other electrical engineer following a specialty. That may sound paradoxical, and sophistical, but it is true; and I have been accustomed to congratulate young telephone engineers on the fact that having to deal with the weakest current which is employed industrially and thus with the most sensitive instruments, they must also be familiar with the operation of all other currents, and the systems wherein such other currents work; so that whenever any question arises, they may be able to handle it with intelligence and

ability, even though it concern engineering work, dealing mainly with heavy current utilization. It is certainly a fact that to be a telephone engineer of the first rank, a man must also be a good mechanical engineer, and a good electrical engineer on the broadest lines.

I was also interested in and instructed by Mr. Sherwood's description of the training school for telephone operators; by his account of the wonderfully low average of complaints and faults; and by his statements concerning the resignations of operators and the difficulty in maintaining the supply of good ones. Within my own experience, marriage has always been an active agency in depleting the force of operators; and a number of operators have married patrons of the telephone exchange.

Of course, no one at this hour could seriously think of devoting discussion to the paper upon a new subject which Mr. Hammer has brought before us; but I think we can all agree that the " mechanical operator " of which he spoke does indeed have one advantage over the human operator now generally employed. It will not resign to the number of 700 within a year because it is desirous of marrying; and our wildest dreams cannot, I am sure, suggest the conceivability of a telephone subscriber—in any contingency—wanting to marry one of Mr. Hammer's " mechanical operators."

MR. F. E. KINSMAN:—Mr. Lockwood omitted reference to the first telephone exchange established in Boston. He said, if I recall, that it was a connection made by twisting a wire from one post to another. As a matter of fact, I was employed in Boston in August, 1877, and my recollection is that the first exchange was operated by transmitting the message through the operator. If the hour were not so late, I would give you some more points on that subject. That was the first exchange established in Boston.

MR. LOCKWOOD:—There is a brief reply needed to the last remark. The first exchange was established in Boston in May, 1877, through some burglar alarm wires. But of course Mr. Kinsman has observed that my paper concerns the " Evolution of the Telephone Switchboard," and does not in any sense profess to be an historical account of the rise and progress of the telephone exchange system.

MR. KINSMAN:—I will take the correction as to date; but I will say that the exchange was first introduced in Mr. Holmes's burglar alarm office and it was made by the operator taking the message and turning about and talking through the telephone to the party to whom the message was to be given. I was there and helped in the work.

[The meeting then adjourned].

A paper read at a meeting of the Chicago Branch of the American Institute of Electrical Engineers, May 19 1903

SOME FEATURES OF TELEPHONE TRAFFIC AND THEIR EFFECT ON SERVICE.

BY J. G. WRAY.

Traffic, in the strict acceptance of the term, implies the transfer of goods or commodities from one person to another in exchange for other goods or commodities or for money. We, of course, may consider as traffic exchange of ideas over a telephone wire from one person to another and such a construction puts telephone calls within the meaning of the word.

Mr. S. J. Larned in a recent paper before the Chicago Electrical Club enumerated several essentials of good telephone service.—

A vast clientele. It should be possible to reach all of one's friends or business correspondents by telephone. Uniform answering. There should be no long wait for the response of an operator. Rapid and accurate service. The party called for should be obtained quickly and there should be no interruption of the conversation. Communication should not be prevented by busy lines. (Busy calls arise from the fact that two persons desire to talk to a third party at the same time and such instances are common on very busy telephone lines.) Apparatus and other plant should be well maintained. The telephone and its wires should receive proper expert attention with a view of minimizing interference with the service, and when out of order should be repaired promptly. Courteous treatment of the subscriber by the telephone employees and *vice versa*.

Consider first the part the subscriber plays in telephone traffic and in making either for good or for bad service. I am perhaps open to criticism from the laymen when I say that the subscriber's part is an important one and often militates against good service. Who has not called for a number and after waiting for a few min

utes hung up the receiver with imprecations against the telephone service? In the meantime the telephone apparatus has perhaps performed its functions properly and the operator is in a fair way to get the called subscriber. When the latter answers—he may not have answered promptly—and finds no one on the line, he, and not the calling subscriber is certainly the aggrieved party.

False calls are a frequent and annoying source of complaint against the service and are caused in many ways in addition to the one just named. The calling party may give the wrong number or the wrong office. The number or office may be misunderstood by the operator, or the calling subscriber may change his mind and decide not to make the call. In case the call is from a subscriber in one office to a subscriber in another office there is of course always a chance of a misunderstood number resulting in a call for the wrong party.

I recently noticed a curious fact in observing traffic from 10-party-line subscribers in a city not 1,000 miles from Chicago. I noted the extreme smoothness and accuracy of the service, the apparent absence of any hitches or complaints and was surprised when I learned that the operator's load was practically 30 per cent. higher than operators' loads in similar service in Chicago. I can explain this condition only by assuming that the operator had the intelligent and courteous coöperation of the subscribers and this was apparent from such observations as I was able to make during a two hours' visit in the office.

Calls should be answered promptly lest they become lost and the called subscriber lose perhaps a chance for an important business transaction. Prompt answering and short conversations will always tend to keep the line free for other inward calls and will minimize busy calls, which more than anything else are a source of bitter complaint.

Practically 20 per cent. of all calls made are never completed because the line called for is busy. About four calls out of every five are completed properly. This feature of telephone traffic is one of the most annoying to the subscriber, but unfortunately is almost beyond the control of the telephone oompany. Many busy calls result, of course, from the fact that certain lines are in use a great deal of the time. The subscriber may come to a realization of the fact that as the business on his line increases the probability that he is excluding other business calls with a busy signal increases even more rapidly. However, inasmuch

as there is always the possibility that two subscribers may desire to talk with a third subscriber at the same time there will always be calls stopped by the busy signal.

Other things being equal, the busy reports that may be expected from telephone lines will become more numerous and will increase with the number of conversations carried on over that line. In actual practice, however, other factors enter in. The New York City telephones, for example, are reported busy about as often as the Chicago telephones, practically 20 per cent. The number of conversations per line on New York telephone lines, however, is much less than on the Chicago lines. We would therefore ordinarily expect fewer busy reports from the New York lines. The other factors entering in this particular case are undoubtedly shorter conversations by Chicago telephone users and a disposition to rent additional telephone wires where circumstances seem to warrant it. Another factor which has even greater bearing is the fact that the New York City telephone calls are crowded into a shorter day and that hour for hour the lines are nearly as busy as in Chicago.

Leaving aside any further discussion of the part the subscriber may have in that which will militate for good service we have only to remark that if the subscriber would exercise the same courtesy and good judgment in his use of the telephone that he would show under ordinary circumstances in dealing with his business acquaintances face to face there would be a marked improvement in the service and the trials of the unjustly maligned telephone operator would be considerably mitigated.

Uniform answering with rapid and accurate service can only be accomplished by minimizing the work on each call and by giving an operator enough calls to keep her busy and not any more than she can handle properly. The service may be considered as being good when the average answering is in 6 or 7 seconds and when say 95 per cent. of all calls are answered within 10 seconds. This grade of service is obtained only under favorable conditions. The operator must not be overworked and she must be continuously under a competent supervising operator. The practice is to have a supervisor for every eight or ten operators. This supervisor should work under the direction of a chief operator.

One of the requisites of good service mentioned above is that the time and operations required of an operator on each individual call shall be a minimum. Obviously, the

operator has no time for discussions with the subscribers on the merits of a complaint. These are turned over to the supervising operator for adjustment. It is the aim of the operating manager so to control the two factors just named that good service will result. By the proper manipulation of the intermediate distributing board he may, by increasing or decreasing the number of lines that an operator must answer, keep the operators load uniform under the fluctuations of traffic experienced in a telephone exchange. He must also minimize the work and time required of an operator on each particular call. This is done by paring down phrases that the operator must use, by providing machinery to eliminate certain manual operations, and easily read and interpreted signals to keep her informed as to the condition of the line called for, whether busy or out of order, or of the various phases of the connection; and charts to indicate changes of number of service, etc.

In a typical telephone exchange the load curve indicating the volume of traffic shows during the midnight hours a value of from 1/10 of 1 per cent. to perhaps 5 per cent. of the maximum hourly load. This period of light load will vary from 7 to 14 hours, depending upon the location of the exchange and the habits of the telephone users. In the offices of the business district of a city, like Chicago, very few calls are made between 7 P. M. and 7 A. M. Between the hours of 10 P. M. and 7 A. M. the calls per hour will vary from 1/10 of 1 per cent. to perhaps 1 per cent. of the maximum. Between the hours of 7 and 8 in the morning traffic will rise to perhaps 5 per cent. of the maximum. The rise will be extremely rapid, until the maximum load of the exchange is reached between 10 and 11 in the morning. About the noon hour there is a cessation of business and the telephone traffic curve shows a drop of perhaps 40 per cent. below the maximum. After the lunch hour when business has been resumed the traffic curve rises to an afternoon maximum between 2 and 3 o'clock. This maximum will be less than the maximum in the morning and will in a typical office approximate 80 per cent. of the maximum traffic of the day. From 3 P.M. until 5 or 5.30 P.M. there will be a rapid decrease in the traffic load with an almost complete cessation of business at 6 P.M.

In a residence district the slump of traffic at noon-time is not very well marked. There is, however, a decrease in the number of calls made late in the afternoon and a corresponding increase in the number of calls for the telephones of a residence district,

the latter arising from the fact that the head of the house wishes to explain why he cannot come home for dinner, or to announce that he wishes to bring a friend. The evening traffic is also a feature of the residence district. Social calls are made, appointments for the theatre, invitations, etc. Evening traffic of a residence district often continues heavy until 9 or 10 o'clock, indeed, in one of the Chicago offices the evening traffic runs from 30 to 60 per cent. of the maximum and heavy traffic is maintained until nearly midnight. The curve of traffic indicates in a measure the habits of the people in the district.

In the Main office district in Chicago the business day may be said to have begun at 8.30 in the morning. There is a partial cessation of business for luncheon between 12.30 and 1.30 o'clock and the business day closes at about 5.30 P. M. For Central office also in the downtown district the business day is from 8.30 in the morning until 5.30 in the afternoon with scarcely any let up for lunch. Lawyers predominate in the Central district.

In Harrison office the day is the same as for Central and Main, but there is a marked reduction in the traffic between 12.30 and 1.30 o'clock.

The South office business day is practically from 8 o'clock in the morning until 9 o'clock in the evening, and even later, with no indications of a luncheon hour. North office telephone users are satisfied with a shorter day than the people of South office district, the limits being from 8 o'clock in the morning until 8 o'clock in the evening. For West office the limits are from 8.30 in the morning until 9 in the evening.

For Monroe office the traffic shows heavy business from 7.30 in the morning to 6 o'clock in the evening with a distinctly marked lunch hour between 12 and 1. Monroe district is a manufacturing district.

Canal office traffic is largely like Monroe, extending from 8 in the morning until 5.30 P. M., with noon hour between 12 and 1.

Yards office telephone users like those of Monroe office begin in the day early and business is in full swing about 7.30 and continues until 5.30 with noon hour between 12 and 1.

In Wentworth district, out in Englewood, the business of the day is done between 8 A. M. and 6 P. M., with some indication that the people have lunch between 11.30 and 1 o'clock.

Hyde Park and Oakland offices, both in residence districts of similar character, show heavy traffic between 8 A. M. and 8 P. M., with no trace of an hour for luncheon.

Lake View office, also in a residence district, shows the work day beginning at 7.30 A. M. and extending until 8.30 P. M. The habit of carly rising was evidently formed before the advent of the Northwestern Elevated.

A similar comparison of traffic load curves of other cities will be of interest. In Philadelphia, for example, we find the heavy traffic between 9 A. M. and 5 P. M., with lunch between 12 and 1.30.

In Boston the traffic shows a work day from 9 A. M. to 5 P. M., with time for luncheon in different offices varying from one and a half to two hours, between 12 and 2 o'clock.

New York telephone users seem to take life even more serenely than those of Philadelphia or Boston and we find the work day beginning as late as 9.30 in the morning and ending at about 4.30 in the afternoon, with two hours for lunch between and 12 and 2 o'clock.

Telephone traffic varies with the seasons as well as with the time of day.

The Canal office district of the Chicago Exchange shows a fluctuation of 50 per cent. between summer and winter traffic. This is caused by the vast lumber interests of the district, which practically close down during the winter months. There is a heavy rush of traffic in April and May, followed by a 40 per cent. reduction in traffic during July and August. In the fall business increases to a maximum in September. This is followed by a 50 per cent. reduction in traffic, culminating in January. A change in the character of the traffic from Canal district, however, has been noticed within recent years and the wide variations of traffic with the seasons are less marked. This is undoubtedly due to the change in the character of the district with the gradual building up of vacant prairie with residences, small shops, saloons, etc.

The traffic of all offices slumps decidedly during the summer months. There is a reduction of perhaps 30 per cent. during July and August, the vacation period.

The volume of traffic of a telephone exchange is also an unfailing index of general business conditions. This is shown by the fact that during 1894, 1895 and 1896 there was a very slight increase in traffic. With the return of prosperity, however, the traffic has increased by leaps and bounds until now it will approximate four times as heavy as during 1895 and 1896.

In passing it will be of interest to note that for 10 hours per day the traffic of Chicago Exchanges ranges above the average hourly

traffic figured on a 24 hour basis. For the other 14 hours per day the traffic is much lower than the average hourly traffic.

The average traffic for the maximum hour is about 2½ times the average traffic of the day, and perhaps 200 or 300 times the traffic of the hour of minimum traffic. The percentages and ratios of traffic given herein take no account of rushes of traffic for short intervals due possibly to the news of a prize fight, a fire, a panic or a foot ball game. These and the tremendous rushes of traffic always preceding or following every important holiday make a severe test of the resources of the operating plant.

The traffic of Saturday forenoon is always the heaviest of the week and is taken as a basis for the adjustment of operator's loads and the loads on trunk lines. The adjustment of the operator's load must be made with a view of handling the traffic well during the busiest hour of the day. Experience has shown that approximately one-eighth of the business of the entire 24 hours must be handled during the busiest hour.

From the above it can be readily seen that the capacity of the operators and the physical telephone plant must be extremely flexible to take care efficiently of the rapid and extremely wide fluctuation in loads just described.

To the advantage of the telephone manager be it said that the human machine is extremely well adapted to the handling of this fluctuating load. A well-trained operator will frequently take three or four calls in rapid succession and complete them almost simultaneously.

Just a word on the efficiency of the telephone plant. Assuming an efficiency of 100 per cent., when all the subscribers' lines are in use all the time, we find that in actual practice they are working under an efficiency of only 2 or 3 per cent.

Assuming 100 per cent. efficiency when the apparatus used by an operator is in use all the time we find that in actual practice it is working under an efficiency of 25 per cent.

Thousands of dollars worth of multiple jacks lie in the switchboard practically idle. Some are perhaps never uesd.

The traffic of a telephone exchange determines the capacity and design of a telephone central station equipment and the size of its operating force. Changes in traffic whether a decrease due to business depression, a change of contracts to a message rate basis or to any other cause; or an increase caused by new telephone subscribers, by better business conditions or perhaps by a change of policy in the matter of party lines or Private Branch

Exchanges must be met promptly by a corresponding readjustment of facilities and operating force to enable the business to be carried on economically and well.

A paper read at a meeting of the Chicago Branch of the American Institute of Electrical Engineers, May 19, 1903.

CONCERNING THE TELEPHONE ENGINEER.

BY S. G. McMEEN.

Mr. Lockwood's contribution concerning the telephone switchboard, and the discussion brought out by it, form so valuable a portion of the too meager literature of the telephone that the writer makes bold to act as spokesman for those who would record appreciation.

There are two principal values in all statements of fact; one, the record of the truth for immediate information and subsequent reference; the other, the correcting of false impressions. The paper and discussion referred to have gone far in exhibiting both of these values, and at the risk of paralleling what has been said so well and honestly, this item of additional discussion is presented.

The telephone engineer's profession is so varied in its contact with commercial and social conditions that its scope is apparently not well understood even by those practising similar professions. Indeed, the very existence of the telephone engineer is in some quarters denied. Let us look at his work from some of the several sides to see if we may generalize about it.

To many persons, the telephone instrument on the wall is the telephone system, and an art based on so little a thing seems a simple one. Yet there are involved, in even the instrument on the wall, the problems of apparatus-design for electrically transmitting speech at the highest efficiency; for the least and greatest distances without change of local equipment and of receiving speech and signals from distant stations.

Granting that the substation telephone set stands for too narrow a view of the whole matter, and that at least a connecting

line is necessary, it is seen that here is involved a problem of alternating current transmission. Note, also, that this line, in such a system as Mr. Lockwood has described, must do in the best manner several kinds of things such as carrying currents for speech and signaling, and some of these things must be done simultaneously. Owing to conditions of topography and degree of congestion of population, the line may be buried or erected with a wide variety of surroundings. As its insulation, capacity and conductivity have vital bearing on its efficiency. and as they also govern its cost, a responsibility rests with the engineer who controls the design of these points. For example: "If by decreasing the effective electrostatic capacity between wire and wire of an underground telephone cable by *b* microfarads, the efficiency of speech transmission is increased by *d* per cent., at a cost per mile per year of *c* dollars, is the expense warranted?" Instances might be multiplied to illustrate the importance of knowledge and judgment in connection with this costly and important part of a telephone system.

To the telephone instruments and systems of lines must be added the central office equipment, so well described in the principal paper under discussion. Of the switchboard and its appurtenances which make up this equipment, three important features have been pointed out. First, the switchboard is an aggregation of a great many parts; secondly, the parts must inter-operate with complete harmony; and thirdly, the aggregation is often of such size as to compare favorably with the big work of an engineer of any other craft.

In connection with the equipment in general in its relation to the lines in general. The location of central offices, their sizes, now and hereafter, the number, size and character of underground ducts and cables, together with all other elements, must be considered and solved for one conclusion—the giving of the best telephone service at the least cost, now and hereafter. And it is not to be overlooked that the factors upon which the solution depends are subject to change so that such change must be foreseen and discounted if possible

It may be replied that all other engineers must take account of rates of interest, prices of material and labor, density of population, etc., and the possible shifting of values. Granted. But a telephone system must be planned and begun it is believed, a longer time before its development to its ultimate size than most other works of magnitude. Because the speaking current

of the telephone is very small, usually alternating, and so not susceptible of easy and exact measurement, there has grown up the idea that the telephone engineer does not deal with exact quantities, and does not use in his work that accuracy of observation and precision of execution common to the engineering profession. This impression is not correct, for two reasons. First, the speech-transmission current is far better understood to-day than formerly and is determined with a very great degree of accuracy, as also are the many other currents having to do with the operations attending speech-transmission. Secondly, the telephone engineer requires the same observing and reasoning powers which distinguish engineers in general from the men about them in other occupations.

As an instance of the possibility of mathematical and physical accuracy, witness the work of Prof. Pupin in the matter of distortionless circuits. An intelligent mathematical reading of the specifications of either of his patents upon the elimination of the hurtful effects of the electrostatic capacity of an alternating current transmission line is recommended as furnishing conclusive proof of the claims here advanced. Considering the art as caused by and based upon a single device—the telephone itself—it is evident that the great usefulness of the present system is largely due to the coöperation of a great mass of additional circuits, methods and apparatus.

The destiny of the art is to place all the peoples of the earth in speaking relation with one another, it is also destiny that the telephone engineers shall specialize. Yet the assertion is ventured that no other branch of engineering demands so thorough a retention of the general lore of the art by the specialist within the art as does this.

Upon the basis of these thoughts, may we not define as follows:

A telephone engineer is one who practises the design and construction of telephone apparatus, telephone circuits and telephone operating methods, and the correlation of all three into systems of telephone communication.

If the definition be approved, let us then claim a place for him among the engineers of more classical reputation, giving him credit for his accomplishment and our best wishes for his future.

BRANCH DISCUSSIONS.

Discussion at University of Illinois, Feb. 7, 1903.

In regard to Mr. Hammer's paper, Prof. Williams said that intricate automatic machinery required expert attention, instancing the necessity for adjustment and repairs upon linotype machines, and suggesting that the saving in operators' salaries might be required for the pay of expert mechanics. Prof. Brooks thought that the 10 per cent. depreciation claimed by Mr. Hammer as ample for the automatic switchboard would prove inadequate, especially in view of the probable changes in details of construction to be expected. The bookkeeper's 10 per cent. depreciation becomes but 9 per cent. the second year, and about 8 per cent. the third year, hence at the end of ten years the entire first cost has by no means been charged off. He asked if any switchboard built in 1893 would now be worth 35 per cent. of its original cost, as it would have to be on the basis of a 10 per cent. yearly depreciation deduction.

Discussion at Pittsburg, Feb. 5, 1903.

Telephony.

Programme:

President's remarks at the New York Meeting read by Secretary, J. S. Peck.

" An Automatic Telephone Operator," by Mr. W. J. Hammer, abstracted by Prof. S. M. Kintner.

" Evolution of the Telephone Switchboard," by Mr. Thos. D. Lockwood, abstracted by Mr. S. P. Grace.

Exhibition and Description of Arcophone, or Talking Arc Lamp, by Mr. R. A. L. Snyder.

GENERAL DISCUSSION.

The discussion was participated in by Mr. S. P. Grace, Mr. Charles Bradley, Mr. P. M. Lincoln, Mr. Gallegher and Mr. L. Hommel.

Mr. Grace.—Mr. Lockwood in his paper on the Evolution of the Telephone Switchboard has admirably described the manner in which the present perfected arrangement of switchboards developed from the crude switching devices of the early days of the telephone.

Mr. Lockwood has also given a very complete description of a modern common-battery telephone switchboard, and has also shown and described the line of investigation which was pursued to attain this development. It is not necessary for me to add anything more on the evolution of the telephone switchboard, since Mr. Lockwood has covered this matter in such an admirable manner; I shall simply call attention to a few of the great advantages that the common-battery system possesses. We may sub-divide the advantages accruing from the common-battery system into three general heads:

1. Improvements in operating.

2. Economy of maintenance.
3. Quality of service.

In discussing the question of operating, it is, perhaps, instructive to look back and see the difficulties under which the operator worked under the old arrangement of magneto switchboards. The switchboard was arranged with a large number of annunciators or drops mounted on the face of the switchboard near the top. When a subscriber turned the crank at his telephone, his annunciator was displayed in front of the operator, who had to look up at the annunciator, ascertain its number, and then hunt out the corresponding answering jack in which to plug. This kept the telephone operator's head tilted upward at an awkward and disagreeable angle.

In the common-battery system the subscriber merely removes the receiver from the hook, which act lights a small incandescent lamp immediately adjacent to the answering jack belonging to the calling subscriber. The operator in answering does not have to ascertain the particular number calling, but merely " plugs out " the light. This act alone increases the speed of operating from three to four seconds.

Another great disadvantage of the magneto system was the entire absence of supervisory signals, *i.e.*, the operator had no means of knowing when the calling or called subscriber was at the telephone. The only arrangement for disconnection was a clearing-out drop bridged across the cord circuit. It was necessary for the subscriber to ring off when through using the line.

Undoubtedly, many of you have run across the sign painted in large letters on the telephone, " Ring off." But it is human nature to do as little as possible when once you receive the benefit asked for; so, while all the subscribers would ring in to get central, but a very small percentage of them would remember the injunction to " ring off."

In the common-battery system there is placed a supervisory-lamp signal on each side of the cord circuit, which is used to connect together two subscribers' lines. When a subscriber is rung by the operator, one of these lamps remains lighted until he answers. When both subscribers are finished with the conversation the simple act of hanging the receiver upon the hook lights both of these supervisory-lamps, which is a signal to the operator that that pair or cords, and consequently the connected lines, are no longer in use. She will, therefore, immediately remove the connection. If either one of the subscribers wishes to call in the operator during the course of a connection, it can be done by simply working the hook up and down, which flashes the supervisory signal. It is thus seen that for all local connections the operator has complete supervision over the calls.

It is, however, in a multiple office district, such as Pittsburg, where the advantages of the common-battery system are particularly in evidence. In such a district is it necessary to operate

a number of offices and arrange for trunking connections between them.

In the magneto system there were provided no supervisory or disconnect signals on these trunk lines. This made the operation of them extremely difficult and also impaired the quality of the service rendered, since the operators would frequently make mistakes and take down the connection before the conversation was finished.

In the modern common-battery system, when a call is received for a line in a distant office, the operator who receives the call cuts in directly on what is known as a calling-circuit wire, to an operator who is located at the exchange which contains the line asked for. This operator assigns a trunk to be used and at the same time plugs the trunk which ends in a plug and cord into the line asked for. The originating operator, of course, plugs into the other end of the trunk line. When both subscribers are through talking, the disconnect signals are received by the originating operator in the usual manner, who will take down the connection. The taking of the plug out of the trunk line automatically gives the trunk operator at the distant exchange a disconnect signal to show her that the trunk line is no longer in use. She will then remove the trunk line from the local subscribers' line. Similar automatic trunks are provided for use between the local boards and the long distance boards. It will thus be seen that from an operating standpoint the common-battery system removes the necessity of the personal supervision of calls by the operator, automatic signals being the means of warning her of all stages of the connection.

The common-battery system also enables us to increase the operator's load, which means that an operator can answer more telephones than in the old style systems. Our payrolls show that with a first-class common-battery system we can handle the same business with about 20 per cent. less number of operators. The common-battery system is therefore easier and cheaper to operate than the old style system.

Economy of Maintenance.—In the magneto systems each individual telephone was a small edition of a central office power plant. We provided batteries for furnishing the direct transmitter current and a complicated magneto generator for furnishing alternating current for signalling the central office.

Anyone who has had experience in the maintenance of even a small central office power plant will recognize the difficulty and the expense of maintaining these thousands of isolated power plants which were located in each telephone. The maintenance of this generating outfit was from $2.00 to $3.00 per year per telephone. But in the common-battery system all these isolated power plants are done away with, and a single central office power plant suffices for the entire exchange. One large storage battery, consisting of eleven (11) cells, is installed. This main battery is charged from motor-generators from off the lighting

mains and supplies all the current used in the telephone exchange. The cost of all current supply per telephone, including the fixed charges, probably does not exceed $1.00 per telephone per year in a modern common-battery system. The removal of the generators and batteries from the instrument has also cheapened its first cost and maintenance, and the instrument as it exists to-day contains the fewest possible number of parts.

It might be well to remark at this juncture that the successful operation of the common-battery system depended upon the evolution of the storage-battery. We had to have at the central office a source of current of constant e.m.f. and which possessed practically no internal resistance. If the source of power were not constant or contained any internal resistance, all the lines connected with the exchange would be noisy or would have cross-talk on them. As is well known, the modern storage-battery produces a current of constant e.m.f., and it besides possesses a very low internal resistance, these two features making possible the common-battery system of to-day.

In the common-battery system there is a pressure of 24 volts on every line all the time, and any poor or defective insulation will cause a leak of current and consequently the display of the signalling apparatus at the central office.

One of the great objections to the use of common-battery by telephone engineers was the fact that it required superior outside line construction, but this in reality has been a benefit, for with the common-battery system we must put our wires and cables underground and use as little open wire as possible, in order to obtain a good quality of service. Also the current being upon the lines at all times, it acts as a sort of watch-dog to the entire system, and makes those in charge of the plant keep it in good repair.

From the above statements the economy of maintenance of the common-battery system is plainly apparent.

Service.—From the subscribers' standpoint the common-battery system is eminently satisfactory. He is not required to grind a crank in order to signal central. All he has to do is to remove the telephone from the hook which immediately displays the signal in front of the operator. This gives the subscriber practically nothing to do and transfers all work to the central office, where it can be taken care of by skilled operators. It is always possible for the subscriber to call in the operator by moving the hook, and the possibility of his being hung up and unable to get the central office is very remote.

That the subscriber is satisfied with the common-battery system is evidenced from the fact that in ordering a telephone or a private branch exchange he will always tell you "that he wants that system where you take the receiver off the hook and it lights one of those little lamps."

I have stated above that in the old systems batteries were provided for each telephone for supplying the transmitter with

current. When these batteries were new and in good condition, the service from the telephone was good, but after they had been used for a short time, or if the subscriber accidentally left the receiver off the hook and thus allowed the batteries to run down, the transmission from the telephone would be very poor. Therefore, from the magneto system, with local batteries, we never could hope to obtain a uniform grade of service.

It is highly necessary that all of the instruments talk well over both local and long-distance lines, for it is our aim and ambition to produce a satisfactory volume of transmission between all telephones in the entire country. In the local-battery system, if we spent a large amount of money in battery maintenance and kept the batteries in first-class order, the transmission for all local connections would be entirely too strong, although it must be admitted that it would be excellent for the long-distance connections. In the common-battery system the source of current supply is from the central office battery and we can, therefore, regulate the amount of current for each connection; *i.e.*, for all local service we will have our apparatus so wired that the instrument receives sufficient current for local transmission, but when a long-distance connection is put up we will triple or quadruple the amount of current given to the transmitter. Thus, with the common-battery system we are enabled to give an absolutely uniform grade of transmission for all local connections, and for long-distance connections we can give the transmitter the ultimate amount of battery power that it will stand. This, in my opinion, is one of the most important advantages of the common-battery system.

So successful has the common-battery system proved in large exchanges that it is now the intention to carry the work still further and make even the smallest exchanges in country towns work on the common-battery basis. Plans have been prepared for a number of these small exchanges, which will work on the common-battery basis, but which will be provided with no power plant. The necessary current for operating the transmitters and signals will be supplied from the nearest large common-battery plant.

In conclusion, at the risk of being considered too optimistic in my views, I will say that within the next ten years the local battery magneto telephone instrument, with its associated magneto switchboard, will be considered as a rarity in the United States.

MR. CHARLES BRADLEY:—As has been explained here this evening, great improvements have been made in the design and operation of the telephone switchboard since 1880, and also in central office apparatus. It is however, only, in the past ten or twelve years that the planning of installation work has been given much attention, especially from an engineering standpoint. Previous to the advent of

the branch terminal switchboard nearly all work outside of the building of the switchboard proper and the distributing frames was done by the foreman at the time of installation. In fact, the same man wrote the specifications, went into the shop and superintended the forming of cable, such as they were, and then started on the road to look after the erection of the switchboard Up to this time switchboard cable was made on the unicolored insulation principle; *i.e.*, in a twenty pair switchboard cable, all the twenty pairs had one red and one white wire. As you can readily understand, this necessitated the testing of one of every pair of wires before soldering them to the multiple jacks or to any other terminal. This, of course, entailed a great loss of time in the erection of the switchboard. The multi-colored insulation scheme was then devised. This consisted of having the insulation of one of each pair of wires of a color different from all the rest; for example, one of a pair blue, of another pair orange, of another pair blue-orange, etc., until the whole combination was effected. Also a regular form was made so that the same colored wire would take the same jack throughout the multiple. Also it was found, since the framework of the sections was made of iron and more uniform than those of wood, that by careful measurement the cables could be cut and soldered to the multiple jacks in the factory. This plan was tried with great success in one or two installations and thereafter used universally as it meant more accurate work and a great saving of labor on the road.

With the advent of the branch terminal board came the power plant. Instead of the gravity batteries a storage battery was used, necessitating charging machines, a power board and conduit work. This storage battery was used to restore the drops electrically as well as for the transmitters.

As improvements were being made from time to time by different installation men, though each had his own ideas regarding the work and no two installations were made in the same manner, certain of these men were retained in the shop as consultation men and an attempt was made to classify the work and have it done in a uniform manner. More elaborate specifications were prepared, and plans furnished showing the location of the switchboard, power plant, conduit, etc.

When the common-battery board was planned this work increased greatly, owing to the number of cable runs, more apparatus and power plants of larger capacity. It was found that by locating exactly each piece of apparatus that the racks for carrying the cables could be designed accurately and built in the shop, conduit plans be prepared and in fact innumerable details that were formerly left to the installer were now figured out by the engineer before the installation actually started. Particular attention was paid to the arrangement and location of apparatus on the switchboard proper, so that the cable work could be done in such a way that all apparatus would be accessi-

ble and easy to maintain. To-day practically all cables are cut and formed from plans made by the engineer, and are soldered to their respective terminals or jacks before they leave the factory.

Of course, I have taken but a few examples to illustrate the progress of installation work, but I think it sufficient to show the great improvement made in this class of work in recent years.

(COMMUNICATION AFTER ADJOURNMENT BY SIDNEY HAND BROWNE.)

In his closing remarks, Mr. Lockwood, in his article entitled, "The Evolution of the Telephone Switchboard," refers to the complex organization of the modern relay switchboard and intimates that the next step in its evolution may be along lines which will simplify it rather than in a direction involving a radical departure from its present organization.

A partial simplification has been obtained, resulting in a better "talking circuit" and reduction in first cost and in maintenance. Such simplification consisting of a reduction in the amount of switchboard cable required in wiring the multiple jacks to two-thirds of what is required under the system described; avoiding the use of a shunt to put out the supervisory-lamp; dispensing with the use of the repeating-coil in the cord-circuit as shown, and with the third contact in the multiple-jacks.

In the diagram, Fig. 9 (Lockwood's article), it will be seen that the relay which controls the operation of the supervisory-lamp is placed in series on one side of the talking-circuit, although there is no corresponding impedance in the opposite side of this circuit. And although this relay is of low resistance, it will slightly unbalance the line; its insertion in this manner should be avoided if possible.

It is also seen that the test-rings of the multiple-jacks are connected by a third wire running the entire length of the switchboard. If this third connection could be avoided, it would simplify matters and be a desirable improvement. By reference to the diagram attached hereto, it will be seen that this has been accomplished, with a consequent saving in switchboard cable, first cost of construction, and reduction in cost of maintenance. By dispensing with this third wire in the multiple-jacks, we have also been able to use a two-conductor cord instead of a cord with three conductors, as shown in Mr. Lockwood's diagram. This reduces the first cost of cords and their maintenance.

It is desirable, if possible, to avoid the use of the repeating-coil in the circuit shown in Mr. Lockwood's diagram, as it is frequently the case that these coils are not properly balanced; and a very slight variation in the size of the core, or inaccurate winding by the manufacture will cause enough unbalancing to interfere with the proper working of the circuit. The use of this repeating-coil has also been avoided in the system described in the drawing attached.

By shunting the supervisory-lamp as shown in Mr. Lockwood's diagram, when the telephone is taken from its hook, the flow of current through these lamps and their shunts continues and causes considerable drain on the batteries.

Figs. 1 and 2 show two telephones connected through a telephone exchange system whose operation is as follows:

The operation of removing the receiver from the hook of the substation instrument closes the circuit and energizes the line

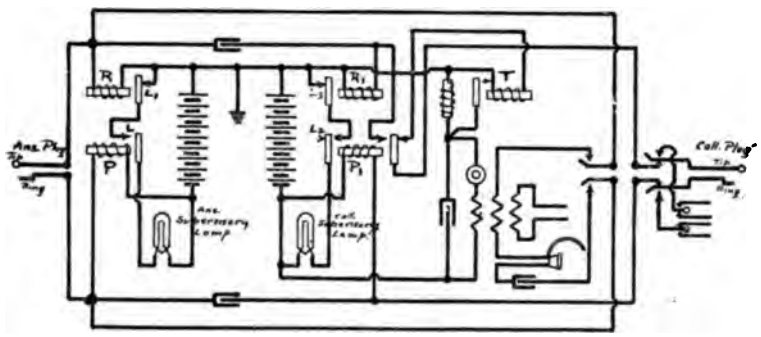


FIG. 1.

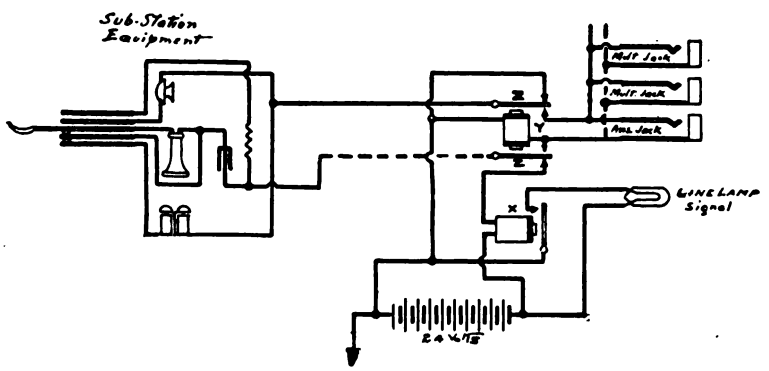


FIG. 2.

signal-relay x in the usual manner. The operator, by inserting the plug in the answering-jack, allows current to flow over the ring of the plug through a relay y, of high impedence, to the ground; this relay being energized attracts its armature, z, and disconnects the line signal apparatus, consisting of relay x and lamp, and also "puts current" on the sleeve of the jack, which will give the busy-test through a relay T placed in the operator's circuit. The advantage of this relay controlling the busy-test is that by its use the operator only gets the signal without con-

veying it to the subscriber who has made the call. The insertion of the plug also causes current to flow through relay P, closing the local contact at L, and allows current to flow through the lamp to the local contact at L on relay R to ground. These relays are of low resistance and are placed on each side of the cord-circuit. When the subscriber answers his call by taking the telephone from its hook, it allows the current to pass back over the tip of the cord to relay R to ground and opens the local contact at L, thus cutting out the supervisory-lamp. It will be noticed that there is a straight through circuit from the tip and sleeve of the answering cord to the tip and sleeve of the calling cord with the condensers C_1 and C_2, inserted. These condensers permit the flow of voice-currents and prevent the steady flow of current from the battery, which simply supplies current for the sub-station transmitter.

The system described eliminates the features which we stated above we did not think were desirable and as shown in diagram, Mr. Lockwood's article. It is true we have introduced the relays R and P and R_1 and P_1, but these relays are wound to a high impedance and are not connected directly in the talking-circuit, but are bridged across it. The circuit is perfectly balanced, which is not true of the circuit as shown in Mr. Lockwood's diagram, and instead of shunting the lamp we open the lamp circuit and save the drain on our batteries.

To anyone who is familiar with the amount of wire necessary in a large multiple switchboard and the consequent greatly increased cost of manufacture, it will be apparent that immense saving can be made by the elimination of one-third of the amount of multiple switchboard cables necessary in the system described by Mr. Lockwood, by the use of two-contact jack instead of three-contact, by the use of two conductor cords instead of three conductor, and in addition to these savings in first cost and maintenance we obtain a much more direct and better talking circuit.

A paper read at the 4th Meeting of the Pittsburg Branch American Institute of Electrical Engineers, February 5 1903

THE ARCOPHONE.

BY R. A. L. SNYDER.

The arcophone or speaking arc is the first successful loud-speaking telephone receiver thus far discovered. The discovery of this property of the electric arc to reproduce speech was first made by Dr. Simon at the University of Erlangen. In the Fall of 1897 he found that by making and breaking the current in a circuit paralleling an arc circuit sounds corresponding to the make and break were reproduced by the arc. Since that time Dudell and Ruhmer have taken up the subject and added very materially to the results. Dudell shunted the arc with inductance and capacity, and produced the *whistling arc*. By varying the amount of capacity and inductance he could produce a note of any *desired pitch*. Ruhmer, copying Bell's photophone principle, used a searchlight for transmitting the light waves from an arc lamp to a selenium cell—a telephone receiver and battery are placed in series with the selenium cell. By this arrangement, speech can be transmitted for a considerable distance by means of the light waves. The *Electrical World and Engineer* of December 20, 1902, contains an article by Frederick Collins describing how Herr Ruhmer transmitted speech by means of light waves to a distance of 12 miles, and in a very satisfactory manner.

Dr. K. E. Guthe, at the University of Michigan, gave an exhibition of a speaking arc before the University Engineering Society, March 28, 1902. He claims to have discovered that the sound continues a short time after the arc is blown out.

The lamp on exhibition to-night is an ordinary Schuster hot wire arc lamp, working on 110 volts direct current. In series with the lamp is an impedence coil. This impedence coil is shunted by an ordinary solid-back transmitter, and the lamp and

coil are shunted by a condenser. The positive carbon is a special kind, being impregnated with foreign substances to produce a longer and more uniform arc. In the arc formed between ordinary carbons there is a great fall of potential close up to the positive carbon; in the arc formed between impregnated carbons there is a more uniform drop of potential all the way across the arc.

Fig. 1 shows a diagram of the circuit.

I have seen a number of arrangements suggested for the speaking arc circuit, but none with a condenser shunt. The condenser shunt adds very materially to the results. We have tried to make an *alternating current* arc reproduce speech; the results were reasonably good, except that it sounded as if the speech were confused with the notes of a jew's-harp.

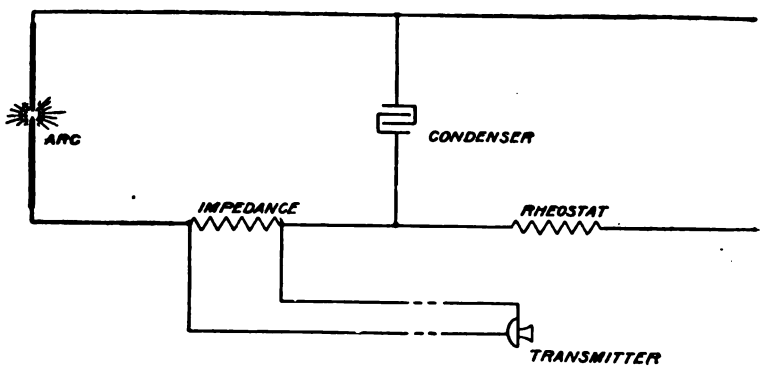


FIGURE #1

Several theories have been advanced as to what causes these sound waves to issue from the arc. The most logical explanation appears to be the one giving the cause as the sudden expansion and contraction of air due to variations in the temperature of the arc.

In speaking into the transmitter the sound waves strike the diaphragm causing the current to pulsate in the transmitter circuit, and this pulsating current sets up similar pulsations in the arc circuit. The temperature of the arc varies as the *square* of the current passing through it. As the arc is composed principally of carbon-vapor in a high state of molecular vibration, it has a very low specific heat. The temperature of this vapor varies almost *instantly* with the current. When this current is pulsating, the temperature of the arc is raised or lowered corres-

pondingly, and the volume of vapor is increased or diminished in accordance with its temperature. Hence the volume of the vapor increasing and diminishing sets up sound waves in the surrounding air.

After hearing this novelty and knowing how it works, the natural question is as to its use. It may possibly be used in the near future for a single speaker to address great audiences with but little effort. This can be done by the speech waves from a transmitter circuit being impressed upon the field of an arc light generator. All the lamps supplied by this machine will reproduce the speech.

Besides being of use in addressing large audiences and transmitting wireless telephone messages, the value of the arcophone as an advertiser is obvious.

Thunder, one of the loudest known sounds, is produced by the electric arc.

LIBRARY DINNER
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

HELD AT SHERRY'S, NEW YORK, MONDAY, FEBRUARY 9, 1903.

At the conclusion of the service of the dinner, President Charles F. Scott said:

It is my pleasant duty to extend to you, ladies and gentlemen, Members and guests, a hearty welcome to our Annual Dinner.

Within the past year the INSTITUTE has been privileged to do honor to two men of world-wide fame. The dinner of last year was in honor of Signor Marconi. It followed shortly after the flashing of a single letter across the wireless ocean. The three dot message was so meagre that it was almost in doubt, but it made Marconi the hero of the hour. A second memorable event was the reception given to Lord Kelvin, whose name is indelibly connected with the first signalling across the ocean. Lord Kelvin told us the interesting story of the early days of the Atlantic cable. He told of the messages which demonstrated the possibilities which lay within the cable and of the accidents which followed and of the difficulties which were overcome after years of patient labor. The cable was not ready for service until eight or ten years after the first message.

It is notable that before our annual dinner of this year every letter of the alphabet has passed across the wireless sea and a lengthy message of gratulation has likewise flashed from President Roosevelt to King Edward of England.

But things move faster in these days than in the olden time. Progress and activity mark every department of life. Scientific discovery, invention, engineering development—all these underlie the awakening of recent years. To such an audience as this I

need not dwell upon the importance of electricity in the new era, nor recite the many ways in which it has led to the revolution of old methods and the evolution of new ones. But I do emphasize the magnitude of the work which devolves upon the youngest of the professions and the need of developing effective men and efficient methods. With few exceptions, the electrical enterprises of the present day, in which $4,000,000,000 of capital are invested, have grown up within the past fifteen or twenty years. Not only that, but the men upon whom this work has depended for its inception, its development and its operation have likewise been developed during the same time. They have worked without precedents. There has been no lamp of engineering experience to guide. Nor have electrical matters stood still. One set of problems is scarcely met before new requirements arise.

Note the evolution in electrical transportation in New York City. Ten years ago horse cars were being replaced by cable cars. Scarcely had their places in turn been taken by the electric surface cars before the equipment of the elevated railway with its extensive and exacting service was undertaken. Before the Manhattan trains were in operation an underground system was planned with heavier trains and higher speed, and long before the Rapid Transit is started, the Pennsylvania Tunnel is undertaken for trains operating under steam railway conditions.

Responsibilities of increasing magnitude confront the electrical engineer. What provisions are there for making his work more certain and more efficient? What means are there for selecting out of the vast and varied sum total of achievement, that which is most worthy to become standard practice? What are the forces which tend to coöperation and advancement among electrical workers and in electrical work?

In reply to these questions I desire to present the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS as a definite positive force for the advancement of the electrical engineering profession and its work. The INSTITUTE cannot take as its type the learned societies of the old school. A new era has come. Modern science and engineering belong to a new order of things. The electrical engineering profession is unique. Electricity enters into so many departments of our modern civilization that its function is difficult to describe. If I were called upon to state the effect of electricity in briefest terms I would reply, *Electricity increases efficiency.* By its use the world's work may be done more quickly and at less cost. The telephone is an instantaneous

messenger, it doubles the work a man can do. The railway motor, the motor in the mine, the crane motor, the motor in the machine shop, bring results more quickly and more cheaply. Electrochemical processes produce cheaper products. The electric light adds to the hours of efficient activity. Electricity has given to the whole world a new method of doing things—of doing them more efficiently in time and in cost. The work of the electrical engineer is not separate and apart, it is interwoven with every branch of engineering, with every industry, with commerce and in a score of ways with the conveniences and necessities of every-day life. The history of the past few years and the tendencies of the present promise an expanding future. Activity is the characteristic of America. It is the keynote of American electrical engineering. The national organization which represents the electrical profession must be an active organization, it must be a broad organization, it must have an ever-expanding ideal. It must take a definite grasp upon present conditions and it must be a positive force in electrical engineering advancement. Its mission is not restricted to the welfare of the electrical engineer alone, but through him and through his work it comes in touch with our modern life in as many points as electricity itself. He was reputed a benefactor of the race who made two blades of grass grow where one had grown before. How much more a benefactor is he who controls the subtle agent that can double the effectiveness of effort in a thousand ways.

The INSTITUTE must be in touch with many men. To one class of our membership are admitted only those who have attained a high standard in the electrical profession. To the other belongs the larger body of electrical workers. The ideal of the one is dignity; the ideal of the other is usefulness.

There are those who question whether the extension of our membership may not compromise our dignity and lower our standards. But I question whether we are truly representative of the Electrical Engineers of America and whether we can exert our proper influence upon electrical progress while there are outside our ranks thousands of electrical workers—not only those advanced in the profession and those prominent in pursuits closely associated with electrical applications, but young men of promise—the engineers of the future. We have failed to catch the spirit of the times and the keynote of electrical progress if we do not realize that we must expand and broaden and progress as well as maintain high standards of excellence. Full member-

ship should be exclusive; associate membership should be inclusive.

The benefits which come from activity and association are being secured through the many Local Branches which have been formed during the past half year. In a dozen or twenty cities and colleges, among INSTITUTE members and among students there are local meetings usually following shortly after the New York meetings at which the original papers with their discussions are reviewed and again discussed by members and students. There is scarcely any other means which can conduce more to the effectiveness of our INSTITUTE in directly strengthening and developing the electrical workers of America than a system of local meetings which brings together men in electrical work and puts the students in educational institutions in touch with present problems.

In its influence upon electrical engineering progress the INSTITUTE is doing a good work. Its Transactions are a continuous panorama of electrical engineering progress. The work of its Standardization Committee and of its National Electric Code Committee has been an influencing factor in establishing definite and uniform practice; its Transmission Committee for securing and publishing extended data upon high tension transmission is now actively at work. A new Committee has just been established for the collection and publication of general electrical engineering data. This will be an efficient medium for the publication of useful and up-to-date data which may be furnished by engineers or by manufacturing companies.

We are looking forward to the time when we may have a building which will be suited to the dignity and the demands of our INSTITUTE. We have been holding our meetings in the assembly rooms of a sister society. On many occasions those standing almost equaled the number of those seated. I am among those who constitute, I believe, a large and growing number among American engineers, whose ideal is a magnificent engineering building giving adequate accommodations to many societies, where each may have the individual facilities which will enable it to carry on its own particular work most advantageously, and it will have those common facilities, such as a large assembly hall and reception room, and a general library, which will be of the greatest common advantage and benefit. The value and influence of such a building is not merely in the convenience of the building itself, even a greater benefit is its influence as a

definite material representative of the general engineering profession and the coöperation between engineering societies and engineers.

President Pritchett of the Massachusetts Institute said at the Stevens Institute inauguration last week that "Isolation indicates a low state of civilization." Let us be civilized! Let us coöperate!

This modern world of ours depends most vitally for its efficient operation upon the engineer whose work enters so fundamentally and so completely into everything which differentiates our material conditions from those of the savage who preceded us. May it not be that our present prosperity is not merely a crest on the recurring cycle of financial ups and downs, but a normal condition in a new era of wealth production, which has been brought about through the thought and effort of the engineer!

It is of inestimable consequence that every means should be afforded for increasing the effectiveness and the efficiency of the engineering profession. As electricity has been a unifying element in modern affairs, making it possible to operate street cars and passenger trains, elevators and printing presses and machine shops, to light the lamps in street and office and home, to illuminate the advertising sign, to heat the curling iron and to cook the luscious steak—all from one system, from one power house, from one dynamo; so, likewise, may not the electrical engineer be a unifying agent among the engineering professions? Let the spirit of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS be—not isolation—but coöperation.

We are here to-night for the special purpose of directing our attention to one of the fundamental departments of the INSTITUTE. We are to celebrate the founding of its Library.

How fitting it is that the national engineering society which without reflection upon its sister societies may claim to represent most closely the modern idea in industrial and engineering activity should have as the foundation and the nucleus of its electrical library, a library for research and for reference, such a collection as the noted Latimer Clark Library which was secured and presented through the appreciation and generosity of our own member, Dr. Schuyler Skaats Wheeler.

What is the estimate which those who have been prominently connected with industrial and engineering work place upon the value of a library? An English engineer in referring to the American iron and steel industry makes this statement: "The

most remarkable industrial development in the history of iron making is mainly the result of two factors, the popularization of practical science by the American scientific journals and the courage and inventive genius of the American iron masters."

We are proud to do honor to the men who have been prominent in this great development. Our INSTITUTE has taken part with other societies in the founding of the Medal in honor of the venerable John Fritz. We are closely related to another man of iron and steel. He has been successful, he has accumulated wealth, but he has also followed the new Gospel of Wealth.

In what way, let us ask, has this man, whose ability has enabled him to accumulate one of the largest fortunes that a man has ever possessed and who has given the best years of his life to a study of problems of industry, of government and of progress, and the needs of his fellow-men—by what channels, by what means has this man found that he can most efficiently employ his wealth for great and noble ends? You all know the answer. The Carnegie Steel Company is not so widely known as the Carnegie Library. And, how fitting it is that the means for cataloging and otherwise making our library useful should have been contributed by the man so highly appreciative of libraries, who has done so much to extend their usefulness and their popularity—Andrew Carnegie.

Our members have not been in the receiving mood alone. A score or two of them, as well as attorneys and companies and societies have been generous, not only in contributing collections of past works, but in several cases in providing endowments for continued additions; and more than one has provided in his will that his technical library shall pass to the INSTITUTE. Such a foundation, accompanied by such appreciation and such interest is well worthy to be celebrated by the INSTITUTE in its annual dinner, with guests so illustrious in the library and the literary world, as those who honor us by their presence to-night.

TOASTMASTER MARTIN:—You have been informed, ladies and gentlemen, by no less an authority than our esteemed President, Mr. Scott, that this is our second annual dinner. I have noticed it as a peculiarity of Presidents that they date everything from the time at which they took office. I did it some fifteen years ago myself (laughter) and have since then wondered what other presidents could find to do. This is not exactly our second annual dinner. There are others of us who have attended earlier feasts, but I think we can say that it is the second occa-

sion upon which we have mustered in such large numbers and with such enthusiasm as characterizes our gathering to-night.

As Mr. Scott has reminded you, one year ago we had the honor and pleasure of entertaining Mr. Marconi, who had just taught the ether to spell the one letter " S." Since that time the ether has succeeded in mastering every letter of the alphabet. When I had the opportunity, a week or so ago, of asking Mr. Marconi to be with us this evening, he expressed his regret that he could not join us, and he said that his time and his hands were full of creating an " Ether Library."

It is due to the New York Edison Company to inform you that circuits and current which furnish us special illumination this evening are supplied through their generosity and courtesy. It is also due to our friend, Mr. Russell Spalding, of the Elblight Company, of America, to state that the beautiful festoons which you see around the room are supplied by Mr. Spalding and the company. The INSTITUTE desires through me to thank the New York Edison Company and its officers and Mr. Spalding and the Elblight Company for the service they have done us to-night.

As I came down Pittsburg Row to-night—I mean Fifth Avenue —I had a dim sort of speculation whether my esteemed friend on the right would really allow me to begin my duties, and would not take from me the pleasure of beginning at the beginning of the programme. These new Pittsburg men are very worthily proud of each other, and it has seemed to me a singular felicity that we should have one Scott introducing a brother Scot to-night, both of them hailing from that nation which has been justly characterized as irrepressible (laughter.) Our President is himself an example of that band of brilliant young engineers who, directed by the finest executive and financial skill this world has ever seen, have made the name of our greatest industrial center, Pittsburg, known throughout the civilized world. So that while the iron and steel industry may justly claim its Carnegie and its Schwab, we, too, will boast our Westinghouse and our Scott. Also our Calvin Rice, and so on, through all the degrees and Lamme-nations.

As Mr. Scott has said to-night, we electrical engineers, we younger men, came late into the world. We found everything pre-empted; the others had been here before us—the earth and the waters under the earth, the coal deposits and the iron mines had already been taken up, and there was nothing left for us but

the vacuum and the ether. We are to-day creating tangible properties out of these intangible elements. But it stands to reason that for the great majority of the members of this INSTITUTE the opportunities are somewhat scarce and scant, the emoluments cannot be large and the salaries will be small—for a few of us more rewards will come through inventions—but to most of us the opportunity to do that which is in our hearts for the INSTITUTE will always be more or less lacking. Once in a while we shall find our " angel " and shall then be able to contribute to the work which the INSTITUTE is doing. I have even ventured to think for myself that had I the good fortune to meet our friend Mr. Carnegie earlier in life it might have been a good deal better for both of us.

There are two good reasons why Mr. Carnegie, our guest of honor to-night, should be with us. One is that he is *one of us*, and I do not think he will chide me if I venture to remind him that some of the first good, honest money that he earned in this world was made in the service of electricity at the key and the sounder, with our good friend, Thomas Alva Edison. And that is why to-night we hang upon our walls our " 73." Mr. Carnegie understands that a good deal better than a good many others of you—

MR. CARNEGIE (sotto voce):—Yes, I do.

MR. MARTIN:—A second good reason why Mr. Carnegie should be with us to-night is summed up in the magic word " library."

" The play's the thing,
Wherein I'll catch the conscience of the King."

said Hamlet, and when I said " library," I ventured to hope and believe I might get Mr. Carnegie to be with us to-night, because he lets no guilty library escape. Our work appeals to Mr. Carnegie who, I venture to assure you, is a discriminating giver and has to be extremely careful as to what he does. Only the other day in this city he awarded to a small boy a gold medal for fishing a man out of the Hudson River. The police of this city tell me that since that time the waters of the North River and the waters of the East River and the waters of the Lower Bay have simply been aswarm with small boys trying to earn another gold medal.

I do not know how Mr. Carnegie regards it, but we are the good little boy who has his first medal, I believe, in the ranks of the engineering societies; and I do not believe that anything would

give Mr. Carnegie a greater pleasure than to see our sister societies do as we have done and join hands with us so that our libraries might be of benefit to the world. I was one of a party at the trial trip of a motor—an electric car—in a village up the Sound a week or two ago, and after the trial trip of the motor we were entertained by a well-known millionaire at his house in company with several others. We were having a good time, and as our legs were stretched under his mahogony he looked pleasantly down the long board and said, " Now, you fellows, I want you all to have a good time, because I don't think many of you will ever be here again." I do not know that it will ever be my honor and privilege and good fortune to introduce Mr. Carnegie to another audience, and you will therefore forgive me if I have made the most of the present opportunity. Gentlemen, our friend, our benefactor, Andrew Carnegie, Rector of St. Andrew's University.

(Three cheers for Andrew Carnegie. The cheers were lustily given.)

MR. CARNEGIE:—Mr. Toastmaster: I suppose he takes precedence even of the President, and I address him first, because he is an editor in addition to being a toastmaster and they rule the world nowadays—and you, my fellow Scot, Mr. President, Ladies and Gentlemen, with especial emphasis, superior to that upon either editor or President, upon the ladies. The engineers of Ameica, set many good examples; particularly the electrical engineers. Permit me to congratulate the INSTITUTE upon having ladies at your banquet—they give an air of distinction and refinement which nothing else can produce.

You say truly, Mr. Irrepressible Toastmaster (laughter), that I have a right to be here among the electrical engineers. Before the electrical engineer was, Mr. Edison, Mr. Barclay and myself, we messenger boys—were. There was no engineering electricity in those days, but I have very delightful reminiscences of those days, and chew the cud over them many and many a time. The greatest change that ever came over me was when I passed from the dirty cellar where I was firing and running the steam engine (and many a time was afraid it would explode, because I did not know whether I was firing right or not, as I was not an engineer), and translated to a telegraph office, where they had clean writing paper and pencils and windows—that, ladies and gentlemen, was my first glimpse of paradise on earth in my early career in making a livelihood. The telegraph office was to me

a paradise, and I began surreptitiously to practise on the instruments in the morning before the operators came. The line was not completed to New Orleans when I first began to practise on the key, but it was completed before I became an operator and received the tremendous salary of twenty-five dollars a month.

The line was completed during the time I was practising, and I called up New Orleans in the morning—the boys got Louisville to connect—that I might say N. O. G. M., New Orleans, Good Morning, and the answer came back "Good Morning, Pittsburg." I said to myself, this is what Swedenborg, that wild Swedish seer, said about heaven, "space is annihilated." So when I see Mr. Edison sitting there and Mr. Barclay, and think of us three; with the privilege of mature years I turn to you and say, "Boys, you are modern, you're a new generation; we are your pioneers, your predecessors. But looking at you and knowing what you have done, no father was ever prouder of his boys than Edison, Barclay and myself are of this generation which has succeeded us."

I have been looking you all over—well, with an occasional glance at the ladies, for which I hope I may be excused. Gentlemen, America has been first in electricity. As Mr. Martin has truly said, you came late upon the scene. To Britain, the other half of our race, we are indebted for all the great inventions upon which depend the material progress of the world. Our advance is focused upon the steam engine of Watt, with one arm spreading over the sea in the boat of Symington, seven years before Fulton, and another arm spreading it over the land in the locomotive of Stephenson. That is the triad upon which the material progress of the world rests, and that was before we of America were. I may remark that all three of these gentlemen were Scotch. I called Mr. Martin irrepressible, and he is asample of the American. The American does not get left; he does not take "no" for an answer; he knows how to court a woman—"no" doesn't mean anything; he knows how to court fortune and he knows how to get a man to a dinner after he has declined three times. The man who wins is the fellow that says to woman, or to fortune, or to the gods themselves, who refuse, "Don't believe you; you don't mean it." The American says "I am going to get there anyhow," and that is what the American does. You take Edison and Stanley and Thomson and you take Scott and Martin and other great lights I see around me—there were no

corresponding men in the old branch of the race, it takes the electrical atmosphere of America to produce such electrical forces as these men, such hustlers. One man has just said to me, " Mr. Carnegie, that man Martin is what you say—but he came from Jamaica." That puzzled me—Jamaica, an Englishman. Well, there is no saying what you can do with a Scotchman or an Englishman if you catch him young enough. Mr. Martin said to me, " Mr. Carnegie, I feel a bond of sympathy with you "—this is Martin's style—" there's a bond between you and me, my mother was a Scotchwoman, of Edinboro." That accounts for Martin.

The toastmaster mentioned St. Andrew's University—there was another Scotchman greatly honored there last October by being made a doctor—Graham Bell—another inventor; so that even in electricity do not forget that there is a little Northern half of an island in the North Sea that is not to be left out of account very often when anything good or great is to be done.

The President struck the keynote of the success of the American. I have often taken occasion to say—and I have known both lands well—the American men, this body of electrical engineers, for instance, are the most coöperative men, I believe, that exist to-day. You remember what Emerson said about the Briton—every Briton was a little island by himself, not communicable with others; they are exceedingly distinctive; they do not coöperate well—they want to go each their own way; but there is this about the American which is different from most other men—he is fair-minded; I don't think the American wishes to override; he is not implacable; is not prone to irritate or to make enemies. I think there is a harmonizing feature about him, which counts for everything in the progress of any great movement, political, social or scientific. And it is institutions like this of the Electrical Engineers which do so much; you cannot over-estimate the influence such organizations exert. You hear a man spoken of as Mr. Pope, your Secretary, was spoken of; I noticed the outburst of applause; that appreciation; that feeling that his fellows, his associates, his friends appreciate him—that man would rather have the appreciation of a few of his friends who know how to judge him than he would have the plaudits of a million who knew not his services. The test of greatness is not the popularity of a man, is not how widely he is spoken of; the true test of greatness—as it is of goodness and personal virtues—is what his colleagues think of him, how they rate him. Take

any of these young men—Edison, Sheldon, Thomson, Fritz, Stanley, or even Martin, though an editor—what do his colleagues think of him? Their approval is the crown of victory that will bring out all the man's reserved force. That is wanting in any nation which does not know how to assimilate, how to combine the social with the scientific. When men who work with you at the bench or at the desk or at the machine become your best friends—and their appreciation, the highest mark that you can win depends upon this —the enterprise in which you are engaged has behind it such a force as nothing else can give it in this world.

President Humphreys, of Stevens' Institute, made a remark to me the other day. He said, " Mr. Carnegie, I read your Rectorial address in which you compared Britain to the other nations of the world. I think you very correctly describe the conditions. I have an American friend who has lived in Britain and has a large business there, and he says that Britain will never equal America, because in America the man who does the work gets recognition, status, social position and everything follows him in America if a man performs service." In Britain it is not so.

I go further than that—our Republican institutions are to be credited with much of the vigor, the ability and the success with which we are going forward to the material supremacy of the earth.

We are all here together in this room. There is not a hair's breadth of difference between any of us. There is not a right or a privilege that one man has that is not every man's right. We are not asking who your forefathers were, or what they did, or what your rank or position of wealth is; we are asking what you do, how you behave yourself, and let all the other nations go into manufacturing, or science, or research, or anything you please—I tell you this nation has a tremendous advantage in that, that we stand, not for the position of this or that family, but for the work of the individual man. That is the card that wins, and that is the reason I back America against all the other nations in the world, because she is a Republic where any man's privilege is every man's right.

TOASTMASTER MARTIN:—Ladies and Gentlemen: When the menu and order of exercises was being made up, my friend on the right said, " Well, by the merest chance Mr. Carnegie may refer to Scotland, and so I would be glad if you would spell the Skaats out in full in my name." As Mr. Carnegie says, it takes a great many nationalities to create an American.

I attach a great deal of interest to and sometimes look with a great deal of pride and perhaps a little pathos on an old and somewhat yellow paper which my good friend Dr. Wheeler and I drew up together eighteen years ago, proposing that the INSTITUTE should have a library, and in our document we mentioned the Latimer Clark Collection as the element and the foundation with which we would like to begin. At that time we were both poor and struggling young men of genius (laughter) and we did not exactly know where the money was to come from, but we had faith in our profession and perhaps a good deal more in ourselves, and so we put that document together and signed it and it is in the archives of the INSTITUTE to-day. I would not have mentioned this, but for the fact that Dr. Wheeler's name is on it. Shortly after that episode our good friend Dr. Wheeler distinguished himself by inventing that which I think is perhaps the most typically American invention of the last century—a machine known as the fan motor, which will distribute more hot air in large quantities in a given time than any other known machine in the world. I was encouraged by the success on my friend's part and was glad to see him move on to higher and larger enterprises. I was glad to encourage all my friends to go into it as a good thing, something which might even prove to be a gold mine. Dr. Wheeler's success is known to you all, for he is one of those who, as Mr. Carnegie has said, has carried our name as engineers, inventors and designers of machinery around this great globe. In doing that, I venture to hope and believe Dr. Wheeler has achieved a competency; at least he gave us a faint indication of that fact when he purchased the Latimer Clark collection for us. I shall never forget the thrill of satisfaction I had when, on going to the telephone one evening, I heard his voice at the other end of the line, and he said: " Martin, I see the Latimer Clark collection is for sale at last. Do you remember what we did some years ago? I wonder if we can get it for the INSTITUTE? " I think it was within the brief space of two weeks that we had the much-coveted Latimer Clark collection. (Applause.) Gentlemen, the Latimer Clark collection is now yours, thanks to the generosity and public spirit, and the altogether altruistic and disinterested action of our Dr. Wheeler. Now, we have had gifts from men outside of the INSTITUTE and are glad of them and proud of them, but we have to do something for ourselves. Dr. Wheeler and I, since preparing that document, have seen the investment in electrical apparatus rise from

less than $1,000,000,000 to $4,000,000,000, and we venture to hope that at least a portion of that wealth will be turned into the treasury of the INSTITUTE. Only yesterday, in the Sunday paper, I read a cable despatch which stated that this wonderful radiating material, known as radium, was being sold in London at the rate of $900,000 a pound, chiefly to American electricians, and I could not help wondering how many of them were standing in line. I know I was not—I was too busy buying coal—but if we have men in our ranks who can thus afford to take up radium at that rate, surely we may venture to hope and believe that they will also purchase for us a little of that intellectual radium, that infinite, brain power of the intellect represented and preserved in the library.

No pleasure that I enjoy to-night in discharging the lugubrious duties of toastmaster will afford me a keener and deeper thrill than now to present to you and to ask you to receive him with cheers three times three, our fellow-member, Dr. Schuyler Skaats Wheeler, the founder of the INSTITUTE Library. (Three cheers were given for Dr. Wheeler.)

DR. WHEELER:—Mr. President, Ladies and Gentlemen: I shall not say very much about the Clark collection, because I do not know much about it; and if I had realized at the time of its purchase that it would result in my having to stand up here to-night and do an after-dinner stunt, I think I would have kept clear of it altogether! I did examine the exteriors of numerous enormous boxes at the appraiser's office and watched the Collector of the Port while he ripped open their hermetically sealed linings and read all the books, most of which are in Latin. As books that are over twenty years old are entitled to free entry, he was about to say, " I do not see anything here to collect on," when he came across a couple of tons of the current issues of the electrical papers, the *Review*, of London, and the *World*, of New York. He then said that I must pay duty on these. He asked me how $125 would strike me, and I said it did not strike me at all, but as I was tired of waiting I would pay it. Then I went away. The next day I received a bill for $250, and went down and made some remarks about it. Then I was told the whole thing had been passed and now no power on earth could change it! That is about the way the books got into the city.

When I first began to take notice of things electrical, I thought I would like to know something about the telegraph and so I turned to my encyclopedia and read up on the subject, and there

I found the telegraph described as a series of towers spreading across the country several miles apart, depending on whether the country was hilly or not, each tower carrying a swinging arm. (This is a long story, but I have the point in view.) The operator in one tower would watch the arms in the next tower and when its arms were moved he would move the arms in his tower accordingly, and in that way signals were transmitted across the country by the process now called "wig-wagging." I made up my mind it was time to purchase a new encyclopedia and did so, and then the publishers of the encyclopedia asked me to re-write the article on Telegraphy. I had to make it fit the same space that the old article had occupied so that they would not have to change the page numbers. That was more difficult than describing the telegraph. This was the method of signalling used in England in 1816 and in France, at any rate according to Dumas in his Count of Monte Cristo. Shortly after that time a scientific man named Francis Ronalds invented an electric telegraph. His telegraph consisted of 400 feet of wire laid underground, with a clock at each end, but in place of the hour marks on the dials of the clocks were the letters of the alphabet. He would send a spark over the wire, the operator at the other end would see what letter the hour hand pointed to, and in that way they started out on a system of electric telegraphing. The Government at that time in England was relying on the wig-wag telegraph for signalling from London to the dockyard at Portsmouth. Ronalds was anxious to get the Admiralty to take up his new electric telegraph, and he made a great many efforts to get the authorities interested in it. Finally, they turned him down in the following rather remarkable message from Sir John Barrow, Secretary of the Admiralty:

"Mr. Barrow presents his compliments to Mr. Ronalds and acquaints him, in reference to his note of the 3d inst., that telegraphs of any kind are now wholly unnecessary and that no other than the one now in use will be adopted.

Admiralty Office, 5th August, 1816."

Francis Ronalds was a scientific man. He was director of the Kew Observatory, a man in delicate health, and also of a very sensitive disposition. This episode caused him to leave electricity entirely. He went to Italy and remained there for ten years and during that time he amused himself making a very fine collection of electrical books. He consulted the book dealers all over the world and got them to send him lists of what they had that was attractive and he prepared a very fine catalogue of all the elec-

trical books extant. He left this library to trustees to be presented to the British Institution of Electrical Engineers. A few years before he died he was made a Knight. Up to this time this was the finest electrical library there was, but unfortunately the trustees did not present it promptly to the Institution. They kept it about ten years and there was more or less haggling about it which gives the matter rather a bad taste, but finally the British Institution received it.

Then Latimer Clark, who had been collecting books, kept on adding more and his correspondence and records give every indication that he was very anxious to make a finer collection than Ronalds. All through his catalogues and correspondence are notes everywhere such as " This book is not in Ronalds'," etc. Evidently the desire to surpass Ronalds's collection was one of his incentives in making his own a fine collection. This in a way is the history of the gathering together of these, our books. A few years ago the executors of Mr. Clark wanted to dispose of the books, and some friends of mine, wishing to enlist the support of a well-known patron of libraries, thought they would write him a letter calling his attention to the fact that this library could be had. They then conceived a second thought, which was that it would be very nice to have a newspaper clipping to enclose with their letter. They did not have such a clipping, so they deliberately set about manufacturing one by writing up an article, pretty nearly a column long, describing the library, which they published in their paper. This was to be cut out and sent to this prominent patron of libraries, but in the natural course of events a regular issue of the paper containing the article fell under my eye and I called up the proper source of information and found who had the books. I cabled for them and got them.

I think the matter of appreciating these books is a very hard subject. They treat of all sorts of things. It is impossible to read them all—I know I cannot; and in fact, from reliable information, I understand that the INSTITUTE itself has employed an expert guide and interpreter to tell it what the books are. There are very many interesting things in the collection. Of course, there is the first book that was ever printed! And then there is the first book that was ever printed which mentions in any way electricity or magnetism, and then there is the first book that was ever printed in English, which mentions anything on the subject, and then there is the first book that was devoted entirely to electricity and magnetism, that is, was issued as a

separate treatise on the subject, all previous books having only incidentally mentioned it, and so on, through an innumerable list of books that have some special interest. Then there is the book which Galileo wrote containing sentiments which were not altogether approved of, and for which he afterwards did time.

I am very enthusiastic about having a good collection of electrical books in this city, and I am delighted to see that the subject received such warm support all around, that there are so many contributors and such extensive contributors, because there is no question that this city is destined to be the electrical business centre of the world, if it is not now.

TOASTMASTER MARTIN:—President Scott has received this dispatched from Cincinnati:

"The Cincinnati Branch assembles to-night fifty-five strong. It extends greeting to the parent society and its honored guest. Tell Andrew Carnegie we can use a library too."

MR. CARNEGIE:—Hand that over to Wheeler.

MR. MARTIN:—I like to witness the emulation or rivalry of great, generous souls. I did not suppose for a minute that either of them was through. Our last speaker in his remarks has touched on the scope and extent of our INSTITUTE Library, and it is really remarkable the manner in which it illustrates the sentiment which is attached to the next toast, namely, "The Unity of Science." An electrician never knows where to stop reading in order that he may add to his store of useful information. My good friend and old instructor in electricity, Mr. Thomas A. Edison, told me once how he began reading in the free library at Detroit, a mere bit of a boy, but still an omnivorous reader, and having no one to instruct him as to the pursuit of his studies he began at the bottom of the first stack, at the end of one shelf, and read straight through fifteen feet of it. He was about to begin on the second fifteen feet, when the librarian thought it was about time to investigate the proceedings of that extraordinary youth.

About a year or two ago I was again impressed with my good friend's, my hero's omnivorous appetite and thirst for knowledge, when being in his library I happened to say that I had never seen in print that I could remember the original statement of Joule of his famous law. The "Grand Old Man's" eye gleamed, and he pulled out a book and read to me there and then the identical passage about which I expressed a little curiosity.

I sometimes wonder what is going to happen to the publishers when this library furore gets through. An old friend of mine

whom Mr. Carnegie will remember, the late James D. Reid, once told me how, when building the telegraph line through to Pittsburg and finding that the circuit was leaking, he determined to insulate it and immediately proceeded to smear the whole wire with beeswax. He says that never since have the bees all down through the Alleghenies and the Valley of the Monongahela had such a boom time as they had that year. Our good friend, Mr. Carnegie, has been beeswaxing the publisher's circuits for a long time.

We have with us to-night to respond to this toast one who is not only distinguished as a publisher, and especially as a cataloger, but one whom we are glad to welcome again as one of ourselves and as an old Edison man, Mr. R. R. Bowker, of the *Publisher's Weekly*.

MR. BOWKER:—Mr. President, the Irrepressible, Ladies and Gentlemen: I am not quite sure of good standing in this goodly company, because I cannot claim, like Mr. Carnegie, Mr. Edison and others who have accomplished things, to be a reformed telegrapher. There used to be a book entitled, "Men Who Have Risen." I suppose the next generation will read that book as "Men Who Have Telegraphed." But I can bring one "character" to this occasion. In the antediluvian days of the New York Edison Company, when I did duty as its Executive, there was a public-spirited and private-spirited gentleman who had just finished his palace on Fifth Avenue but had not yet occupied it, when he received an electric light bill. He came in great excitement to the Edison offices and insisted on coming to headquarters with his light bill. He said that he had asked the architects about this bill for $346, and was told that they had been moving furniture, etc., on the elevator, but could not account for more than half of the bill. I asked our friend if no one had noticed a decimal point between the 3 and the 4, whereupon he paid his bill for $3.46 and went away to ask further questions from the architects. Afterwards I learned that in his judgment I was the only man in New York who knew anything about electricity—I suppose because I was the only man who had ever shown him how to reduce an electric light bill. But I come before you rather as a member of "the executive profession," who has had something to do with electricity in the course of a varied business career, to speak to you rather from the layman's than from the engineer's point of view.

So short a time ago, Mr. President, as when I was in college, our electrical equipment consisted chiefly of a galvanic battery,

warranted to kill fourteen freshmen in series—we never tried it to its full capacity—the Geissler tubes which Prof. Pupin later turned to so good purpose, and never returned, and an electromagnet which under the inspiration of that same battery would grow a beard of a hundredweight of tenpenny nails in less than half a jiffy. That was a great outfit for those days, and the contrast with college equipment of to-day tells, in a sense, the story of electrical development. To think that one person within this generation—as has been my personal experience—should have handled, reverently, from the hands of the noble woman who dictated that inspiring message, the first telegraphic despatch with its wonderful prophecy, " What hath God wrought?" should have known the man commercially responsible, Cyrus W. Field, and the man electrically responsible, now Lord Kelvin, for the first Atlantic cable; should have received, at the Como exhibition commemorative of Volta, one of the first despatches without wire, and later have sent wireless messages from ship to shore; should have witnessed Elisha Gray's earliest showings of his form of telephone from room to room of a private residence; should have seen Prof. Pupin in his laboratory working out that wonderful tuning system, extending the range of the telephone, possibly across sea, for which tune the piper had to pay a quarter to a half million dollars; should have seen a great electrical system grow from nothing until it reached and outreached a million lamps' equivalent; should have known the first electric station in which Edison did his pioneer work and in which he discovered that inevitable element in every electrical enterprise, the electric " bug "; should have seen the generating unit grow from Edison's wonderful " steam Jumbo " of 150 horse-power to the 300 horse-power, the 600, the 1200, the 2500 horse-power unit, until now the unit of 5,000 horse-power, the size of the great turbines at Niagara Falls, is that which you see in many great electrical stations to-day—to think that all this which I have indicated has been accomplished within the compass of one short generation, that is an epitome in itself of the progress which this industry of ours has made—an art new-born, responding to a science new-born. For throughout all electrical progress, this creating of a new art, the important fact has been the mutual responsiveness of science and art, the flowering of science into art, and the response of art to science, step by step.

All the way along from the days when Lavoisier and Berzelius, at the beginning of the nineteenth century, gave to chemistry

reasonable names and its algebraic language, how wonderful has been the growth of every science until at last all of them seem to have culminated and concentered in our own. And all that progress has been a progress in and toward unity, a progress also at an accelerating speed, for it seems as though, as the last century put away its hundred volumes on the book-shelves of time, that century had told us more than all the centuries that had gone before, the latest generation more than all the generations that had gone before, the latest years more than all the years that had gone before. And now, progressing in and toward that unity, we face the questions which the nineteenth century has left for the twentieth century to solve.

With all its achievements, the nineteenth century has done the one great thing of putting question-marks for the twentieth century to answer, and it is that to which the twentieth century is now applying its talents. It seems as though Nature has no exceptions to her laws, as though every time she presented an exception it is only with the query into what greater law does this fit. Let me take one example which has already been touched upon to-night. Two or three years ago in London I remember being seated at a dinner given by Lord Kelvin, between himself and Becquerel, soon after the great French chemist had made the start in his contributions toward our knowledge of the extraordinary properties of uranium, and Lord Kelvin said that Becquerel's discovery of the radiant properties of that element seemed to be the first note of query that had been put against the conservation of energy since that great doctrine took its place in our scientific knowledge. To-day the real nature of the " Becquerel rays " is one of the chief questions put before us, and those Americans who are in line in London to secure their share of radium at $900,000 a pound, will be asking questions concerning that still more wonderful newly-discovered element as to what it really does, whether really and truly it is throwing out its atoms at a velocity equal to that of light so that in the year 2003 they would have melted a column of ice a quarter of a mile thick, the supposed limit of its ultimate energy, or whether it will be proved that its light or radiation is simply another phase of radiant energy. Of course it is radiant energy with which the electrician, above all, is dealing. When we glance along the sciences, there seems no longer any division line; the chemist and the physicist are one, the atom is itself perhaps only a mode of motion. And the *chef* who has supplied us this excellent dinner

would be without his calling were it not that somehow in this marvelous electrical organization, the human body, the nerves which translate the sensations of food apparently into electrical vibrations, send the telegraphic messages to the brain. The physician of to-day will tell you that his eye is fixed most keenly upon these new developments of radiant energy which have such marvelous relations to the human body, and it seems that we may be on the brink of a discovery that physical substances are known to us only through the messages of their vibrations, which have to be translated into terms very like electricity before we recognize them at all, so that all the problems of science find the path of unity a possible answer in terms of electricity.

It is interesting, Mr. President, that at last the INSTITUTE has recognized practically through the gift of those generous donors, Dr. Wheeler. Mr. Carnegie and others, the desirability of bringing together into one place all the knowledge that can be had in books as to what electricity means, because the knowledge of the past is the only safe ground for advance into the future. The generations past built cathedrals; the library is the cathedral of to-day. And no nobler cathedral could be made than one in which the representatives of the several engineering sciences should meet together with the equipment of a great library which would answer all the questions which could possibly be asked of the past. So not only the INSTITUTE, but the whole electrical profession, is to be congratulated that this INSTITUTE has arrived at the point where a great library is to be its next work, and I think every one should be stimulated to give of their own collections to make this collection adequate and approximately complete, and so far as possible, to concentrate all knowledge in this field.

To me one of the most beautiful symbols in the world exists in the old Mexican city of Vera Cruz, the City of the True Cross, where there were more churches than modern life had time to use. One of those old churches to-day represents what we have come to know as the library spirit—what we also know as the Carnegie spirit—for the lower part of it is used as the home of a public library, and its tower for a beacon which throws its light far out upon the sea. So, with the foundation of the library as a basis for the far-reaching beacon of electricity, how much will this INSTITUTE mean in the future! And let us hope that everything that it does will give to its members the inspiration of the widest thought of the man of science. May I read to you, in conclusion, a few lines of alliterative Saxon fashion, in which I try to suggest the range and the unity of his work:

THE MAN OF SCIENCE.

" He weaves the whole world one with weft of wire,
Till at one touch it throbs and thrills and thinks,
Then wins the wireless wave to hail and hark.
For him the lightning fills Aladdin's lamp
And fiercest force is free or fast at will.
One beam builds bridge across the boundless blue
And brings him secrets of the spectred stars.
Rev'rent he reads rude records of the race
And from faint footprints fashions the full frame.
Watching with wisdom's eye the witless worm,
He scorns not from the small to grasp the great.
Seeing sure-eyed beyond the scope of sense
And tracing throughout all the timeless throught,
Strong-souled to serve, and by the service save—
Such, Science, is the seeker at thy shrine ! "

TOASTMASTER MARTIN:—In the creation of the INSTITUTE Library we are glad to secure expert advice of the highest order; and I think we can say we have that when we call upon our friend Dr. J. S. Billings, Director of the New York Public Library, to speak to the toast, " The Technical Library." I have much pleasure in introducing Dr. Billings to address himself to that subject.

DR. BILLINGS:—Mr. President, Mr. Toastmaster, ladies and Gentlemen: In the early days of the exploitation of electric light systems in this country, an objection urged by the engineer of one company against the light of another company, was that the other company's light was surrounded by " so much non-luminous verbosity," a very serious objection. In the light which I am to turn on the subject of technical libraries, I am going to endeavor to avoid it by being very brief.

Technical libraries, that is to say, collections of technical books, are pretty old. I suppose the first ones were theological libraries; but technical libraries in the modern sense began with the patent systems, and the best general technical libraries in existence to-day are those connected with the patent offices of various countries. The relations of technical libraries to great general libraries are of some interest. I have looked over the collection of technical books in the Library of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, and find that it is very complete in the separate works relating to electricity alone, and its applications as it stands to-day. Much literature on this subject is contained in that of other departments, so that the investigator may wish to see the transactions, journals and reports of learned societies

that at the present time do not perhaps seem to have any connection with this work. These you are accumulating and you have been extremely fortunate in being able to get some of the great sets of such reports and journals. Now, these journals and transactions of the learned societies in London, Paris, Berlin, Vienna, etc., are in the New York Public Library, and as your library is not yet well known, there are more engineers who come to read these volumes in the New York Public Library than to read those in your library, and at first sight one might think it raised the question which it is said was raised after the discovery of the law of the conservation of energy—a statement of the mechanical equivalent of heat by the first engineers who went to the infernal regions and after looking around inquired if there was not a tremendous waste of energy there.

I think both libraries are necessary; the public library and the special library. The special technical library of the special society, if so managed as thoroughly to enlist the interest of the men who use it, will receive many things which would not ordinarily come to the public library. I found that to be the case with the medical library in Washington. This technical library is now the greatest and most complete medical library in the world, and this is due to the fact that it was kept separate from the Library of Congress. The doctors did not take any special interest in the books when they were in the general collection, did not feel bound to look after them or give service to them. There should be what has been talked about here to-night—coöperation between the two. It is not necessary both should have everything. For example, take the book referred to in the programme to-night, that of Albertus Magnus, printed in 1494. That is not primarily an electrical book and is of small importance in connection with electricity. It is in the New York Library for another and different reason. So it is with a number of other books which are in your library because there are two or three lines in them about electricity. There are some very old books that it is not worth while for both libraries to have. The first great encylcopedia, the very first, is in the New York Public Library, but it is not in the INSTITUTE Library, and it will be many years before it will be there, no matter what price you offer for it, and it is not worth while for you to get it.

The men who consult the books in the Astor Library want the collections of patents, books on physics, transactions of engineering societies, etc., to refer to. Most of them want the latest

periodicals. That is the demand you will have in your library—it is the latest periodical literature they want; the text books are of small interest for the engineer who is up-to-date in his work. He wants the very latest literature and that is what he goes to libraries for. There is plenty of room in New York for two of these collections; and in the case of patents it would be good for you to have collections of the electrical patents. I do not know anything that is needed by the engineers of New York in the way of literature to-day so much as a full collection of the German patent specifications. We have the English, French and American; the German specifications are not here. Should both the INSTITUTE and the Public Library endeavor to get them? I think not. The INSTITUTE may confine itself possibly to getting the specifications for the electrical patents, and yet there will be many specifications for other patents that your members will want to read, and it is hard to say what they will want to read. If they want anything that you have not secured for your library, the chances are that we shall have them at our library. So I think there is plenty of room for both; and abundant opportunity for putting energy into both.

Your library is in first class condition now; and I congratulate you heartily upon it and upon the way in which it has been taken up. I congratulate you upon another thing in connection with it, which perhaps you may not quite understand at present, but which you will understand in years to come, and which is more important than the books and that is that you have a man who is thoroughly intelligent, zealous, enthusiastic and persevering to look after your library, push it on and take care of it, look after its interests, in the person of the chairman of your Library Committee.

TOASTMASTER MARTIN:—I was glad indeed to hear the reference to the chairman of the Library Committee from one who is the best judge in this country of the value and quality of such work—I mean our good friend and fellow-member, Lieutenant Commander W. D. Weaver. I think it only fair to Mr. Weaver to say that the work which he does for the library is entirely a matter of self-sacrifice and labor of love.

I now have the pleasure of calling upon Mr. Theodore L. De Vinne, who will speak on the subject, "The Debt of Mechanics to Science."

MR. DE VINNE:—Mr. Toastmaster, Mr. President, ladies, and gentlemen of the AMERICAN INSTITUTE OF ELECTRICAL ENGIN-

EERS: I feel as if I were somewhat out of place. If there is any one present who knows less about electricity than I do, his ignorance is deplorable. My business is that of recording and preserving the thoughts and experiments of other people, and not that of trying to record my own; and yet I cannot let the occasion pass by, as I am probably one of the oldest men in the room, without calling your attention to the work that has been done in the application of electricity in a relatively few years, in fact, less than an ordinary lifetime.

It was about sixty years ago, during my last term in school, that I attended the lectures on Natural Philosophy, and there I saw for the first time what we would now call a very crude electrical apparatus. I wondered at it, and so did my classmates—wondered at the incessant and apparently fruitless activity of the machine. One of the class asked the teacher if that electric power or force could not be turned to good account, and be applied to mechanics. The teacher shook his head and said no; that Prof. Page, the scientific expert at Washington, was then trying to utilize it, but so far with small success. The teacher said he had no doubt the time would come when it would prove a success, but at the present time we should regard the electrical machine, and in fact all exhibits of electrical apparatus shown in ordinary schools and colleges, as nothing more than scientific toys. This was in 1842. Fifty years after that I stood in the pit of the Niagara Falls Power Company and gazed with undisguised admiration and astonishment at the gigantic machines that were set up there. I was told it was proposed to send light, heat and power to the distant cities of Rochester and Buffalo. So they did. It is but two years ago that I was at the Pan-American Exposition, and there I saw by the simple operation of turning a key that light, heat and power were furnished in a way that was perfectly unaccountable. It was plain that electricity had become something more than a scientific toy. It was one of the great working forces of the world.

Long before that I had some opportunity to witness the wonderful flexibility of electricity in our own printing house. There was there a little humming dynamo whirling around at great rapidity, that was generating an unseen power, liberating atoms of copper, finer and purer than could be attained by fire heat, and making the exact duplicate of an engraving at about one-tenth of its cost, and I had good reason to be thankful that electricity had been applied to the art of typography. It was something more than a scientific toy there; it was doing work.

I shall not tire you, gentlemen, by telling you of the triumphs of electricity in other directions. You know the story a great deal better and can tell it better than I can; but I do think it is worth while to call attention to the fact that notwithstanding the advances which have been made in many directions of electric power, that there are some teachings of political economy which have not followed the development of machinery, which threaten to make some disturbance in the world; and it is on that point I want to make a few remarks. Horace, the old Latin poet, sharply divided the people of the world into two classes, those who grew corn and those who ate corn. Following this lead the political economists of the eighteenth century and many of the nineteenth, laid down the proposition that all work was the result of labor, and that labor has been understood erroneously by too many people as manual labor only. In my own trade every invention that has been made by science has been denounced at one time or another. At the introduction of the art of stereotyping, the rotary printing machine, the cylinder press, the type-setting machine—these inventions were stigmatized as "robbers of the poor," "taking the bread out of the poor people's mouths." The notion has gained currency, particularly among the more ignorant classes in our own community, that machinery is of great disadvantage to the laborer, that it has made the rich richer and the poor poorer. I dissent from that teaching; I reject it altogether. I contend that the wealth of the world has been increased by invention and machinery, and that their combined influence has tended, not to the debasement, but to the uplifting of labor. We have not outgrown the old false ideas which people entertained some hundred years ago. At that time every man who devoted himself to science and invention was looked upon as an idealist, a visionary and an enthusiast. The working class, if I can so call it, the laboring class, stuck to the idea that these men were practically parasites upon society, and that the working men were the ones who produced the wealth of the world. There never was a greater mistake. To help them to this wrong conclusion some of our writers, notably Ruskin and William Morris, have laid down the proposition that society was at its best when every man was his own employer and did not work for a factory or any aggregation of capital. This has been said in spite of the fact that there are places in the world, especially in the Far East, where there are no large factories, and where manufacturers do not employ

machinery, but in such places as in China, the manual laborers—many of them most expert of workmen—do not earn dimes where machine tenders here earn dollars.

Personally, I am acquainted with few of you, but I understand very well that you as electrical engineers are the conservers and controllers of one of the great working forces of the world. You are not capitalists and you are not manual laborers, and yet you are indispensable to both. Without you capital could do nothing. Without you labor would be only half-paid. Worse than that, without the machinery which you regulate the product of labor would be faulty, almost contemptible. And yet, notwithstanding all the benefit which has accrued to the world at large from invention and from machinery for the last fifty years, the unrest of labor is as great as ever. We have strikes continually. The future of society is threatened. It seems of very little use for any mechanic or any manufacturer to appeal to Congress or to Legislatures. The Legislatures as a general rule are inactive because their members are anxious to secure re-election by catering to the whims of the majority of voters. Samson Brass, one of Dickens' characters, says that the first axiom of the law is to look after itself. It follows that any tendency on the part of the public to stop litigation works great injury to lawyers and is not to be approved. Just so, the merchant and manufacturer can get very little help from the Church. The Church ought to be, by virtue of its mission, the great disseminator of the gospel of peace and good-will; and yet it is now, as it was more than a hundred years ago, when John Wesley said that he found it impossible to reach the two extremes of society—the very rich and the very poor. The Church could not keep its hold on them.

Now it is to you, gentlemen, according to my notion, that we have to look for the maintenance of peace and harmony during this century. As I have said before, you are not capitalists nor laborers, but you are indispensable to both. You are the intermediates that connect discordant forces. You have shown to capital that it is of little value unless there is skill, knowledge and efficiency on the part of the intermediate who secures from capital its due reward. You have shown to labor that it is quite possible for a person without capital or means to qualify himself for a position of profit and honor. Although capital has been called so hard and selfish, there is no class that is more willing to give generous acknowledgment to skill and fidelity. I look to you, gentlemen, as the great pacifiers of existing troubles between

labor and capital. I am sure you will join with me in wishing that the differences which now exist will come to an end. The time will come and it is not far off, when the manual laborer, encouraged by your example, will discern that his true interest is in the encouragement of science and invention, in making himself the ally of capital and machinery, and not its fractious enemy. No class can be more helpful than electrical engineers in the attainment of this result.

TOASTMASTER MARTIN:—The Library of the INSTITUTE at the present time does not include any bound volumes of newspapers. I believe, however, that owing to the rapid manner in which the daily press is becoming the expositor of electrical ideas, it will soon be found necessary to include in the collection at least some of the typically representative daily newspapers. There is none of us who takes up a newspaper in the morning who does not there learn some electrical fact of whose existence he never had the least suspicion. Such men as Sprague and Stanley and Edison and Tesla and Pupin, have all consulted the columns of the daily papers to find new ideas with regard to the possibility of inventions that had never before entered into their wildest contemplation. Dr. Bayles, who is with us to-night, represents this new journalism, and has the advantage over a great many of his compeers on the daily papers in being also an engineer. I wish from my heart that there were more men like Dr. Bayles connected with the daily press in this city, and it is one of the most encouraging factors, one of the most encouraging signs of the manner in which they regard engineering ideas and ideals, that they are willing to trust to such a man the treatment and discussion of the topics which lie nearest to us. It is therefore that I have much pleasure in introducing Dr. James C. Bayles, of the New York *Times*, who will speak to the toast "Electricity in the Daily Press."

DR. JAMES C. BAYLES:—Mr. President and gentlemen: Lest it be supposed that in restraining a natural tendency to try a fall with the toastmaster to balance not merely my own account with him but the accounts of previous speakers whom he has introduced with airy persiflage, I fear the keen and pliant rapier of his wit, permit me to relate an incident which came under my notice while traveling in the East. It occurred in Abyssinia and, besides serving the purpose immediately in hand, is an interesting illustration of the survival of the Roman *lex talionis* among primitive peoples.

Two boys were playing in the shade of the sheltering palm when it was arranged that one of them should climb the tree to detach dates, while the other stood below to catch what fell. It chanced, however, that the boy in the tree lost his hold and it was he and not the dates which fell upon the boy below, hurting him greviously. The mother of the fallee, so to speak, hastened to the Cadi, demanding reparation. After hearing the complaint the Cadi decided that the plaintiff had a case, and decreed that her son, the original fallee, should climb the tree and, letting go, fall upon the other boy, the original faller, who was required to place himself in a suitable and receptive attitude on the ground and await what might happen to him. As I remember, the case was subsequently settled out of court.

This kind of Cadi justice is what the speaker at a dinner may expect who undertakes to have fun with the toastmaster. One who may speak as often as he likes and avails himself of this privilege by speaking a great deal oftener than other people like, has an unfair advantage. Much the better plan for the aggrieved speaker is to follow the excellent example of Brer Rabbit and " lay low " until things come his way. At some dinner at which I shall preside I shall send him a flattering invitation to attend and respond to a toast—and if he is prudent he will decline.

When such an invitation reached me I was told that my toast this evening would be " The technical end of the daily press." That was easy. There is no such end. I now learn that it is " Electricity and the daily press." That is another matter. However, the speaker on an occasion like this who is hampered by the metes and bounds of his toast, has much to learn about acceptable after-dinner oratory. When an expert is through with it, the fate of a toast should recall that of the fox who was found dead near Montclair the day after a meet of the Essex County Hunt, and was shown by the autopsy to have died from fatty degeneration of the tissues due to sedentary habits and lack of exercise.

The daily press does not aim to be technical. It deals with facts, and is quite content to leave to those for whom, like my esteemed friends of the technical press a daily is much too sudden, the leisurely consideration of the reasons for things which the public has forgotten. The qualifications of the technical journalist may not, as some have unkindly assumed, consist in the breadth of his misconception or the comprehensiveness of his misinformation, but he certainly knows a great many things

that are not so, and delights to share his possessions with the credulous reader, assuming, of course, that what he writes is read. Considering that all he knows of what is going on in the world he learns from the daily papers, the patronizing way in which he points out and corrects unimportant and accidental errors, chiefly in the use of an arbitrary and wholly artificial terminology, which have found their way into the hot stereotypes from which newspapers are printed, is very impressive, no doubt, but it suggests the boy at the grade crossing making faces at the express train. Before the boy has screwed his features into the contortion which he deems most expressive of the fact that he doesn't want to go anywhere, and would not ride on a train if he could, the express is a mile away, and the passengers really know nothing about it. The dailies have to generalize very quickly and do not claim to be inerrant; but they do get the news, and that never was and never will be the function of the technical journal. It has quite another purpose.

Judge Key, of Chattanooga, while Postmaster General in the Cabinet of President Hayes, invented a phrase which has outlived his other official service. It was that in which publications of a certain class are described as " primarily for purposes of advertising." This recalls a little story which I should not have had the heart to tell at a dinner presided over by a technical editor, had that gentleman been less indiscreetly facetious in his own remarks.

One day a gentleman from Texas visited New York and in the course of his rambles through the streets he chanced upon an organ grinder with a monkey. (I beg, Mr. Chairman, that you at least will believe that my anecdote is divested of all trace of personality.) The organ was covered with green baize, and on this sat the sad-faced Simian, waiting for what might eventuate. The habit of a lifetime had taught our Texan friend to associate a level surface covered with green cloth with some sort of a game of chance, so he marched up to the instrument and laid down a five dollar bill. The monkey promptly appropriated it, doffing his cap in the perfunctory fashion of his kind. The Texan shrugged his shoulders, remarked that one could not expect to win every time, and laid down another bill. This the monkey promptly pouched in turn, while the delighted musician turned the barrel of his organ as if it was coupled direct to a Parsons turbine. The Texan was not lacking in sporting blood, but he knew when he had had enough, and turned away remarking that

while he did not understand this particular gambling proposition he did not remember ever having been in a game in which the advantage seemed to be so largely with the dealer.

If I am reminded of this when I see the quantities of advertising the technical papers carry, it is of course because the association of ideas will sometimes bring unrelated suggestions into irrelevant juxtoposition. Of course they don't get much for it—but that, as Kipling would say, is another story.

The relation of electricity to the daily press is really much more intimate than might appear at first glance. To cable and land telegraphs we are indebted for a deluge of stuff, and the enormous expense attending its getting by the hundred agencies employed in collection and transmission leaves so little for the employment of writers of large experience and ripe judgment that we who belong in that classification have to struggle along on beggarly salaries of ten or twenty thousand dollars a year. Now, gentlemen, I ask you as man to man, what can you expect when literary talent is thus starved that bloated monopolies like the Anglo-American and the Western Union may bleed us as they do? Our hope is in Marconi's cent-a-word promise, and may he live until he " makes good."

For the ephemeral and sensational features of the daily press the electrician is to blame. For its influence for good, its incalculable power in shaping public opinion along right lines and its beneficient function in the upbuilding and safeguarding of civilization, the journalist who is proud of the fact that he knows no more about electricity than a cat knows about pearls, is entitled to the credit. When he disappears from the scene of action and leaves the world to regulate itself, anarchy will succeed order and chaos cosmos.

The characteristic and beautiful modesty of this statement will, I am sure, commend itself to your appreciation like the perfume of the violet or the bashful pendulosity of the lily of the valley.

It has been the pleasure of many writers, and among them none more charmingly than the late Charles Kingsley, to tell us how the hoarded sunshine of the early world, locked up in the lush vegetation of the carboniferous period, flashes forth again as light and heat when the carbon atoms of coal upon the fire rush to the embrace of the oxygen atoms they parted from when the world was young. We trace this perennial miracle in all the phenomena of combustion, and wonder at it. How much more

startling the transformation when the carbon of printers' ink is mingled with thought and, fired by the Promethian spark of inspiration, as light and power flashes from the printed page to illuminate the world and drive the wheels of industry with constantly accelerating speed. This is what happens when the clang of the press produces a daily paper.

But of the technical journals— Well, some of us may at times find ourselves repeating the sage remark of the little girl, " Mamma, I do love my donkey, but he'd be ever so much nicer if he wouldn't donk."

TOASTMASTER MARTIN:—While I sat here just now, a message came up from the floor that there were five or six excellent jokes to be had for a dollar and a half. I was trying to locate a possible purchaser at this board. Since I heard Bayles, my own mind is satisfied on the subject. But one word in parting. I promised our friend, Mr. Weaver, who is sick at home to-night, to bring with me one message from him, and that was if you happen to know a millionaire would you not please catch him and get something from him on behalf of the library; but you want to be sure of your millionaire. I remember a little incident in this city, at least it was in the daily papers, and therefore I give it due credit, with regard to an attempt made to collect a million dollars form a somewhat cold-blooded millionaire whose name, perhaps, it would not be sage to mention. The gentleman who had this loan in mind started out with a little dynamite in a handbag in order that, with its assistance, he might be able to dislodge the rocks. The dynamite was used with an explosion which left the vicinity of Trinity Churchyard something like a section of the New York subway. The millionaire emerged from the scene with his shirt front and his bank balance intact, but as for the would-be collector, from that day to this he has not been able to collect even himself. Other and more successful attempts have been made and there are those who have found a touch of our friend Weaver absolutely irresistible. There is no one whose generosity has been more deeply appreciated than that of Mr. Edward D. Adams, who is with us at this table to-night.

And now, ladies and gentlemen, with this word of advice, encouragement and good cheer, from our Chairman of the Library Committee, I have the honor to declare the " Second Annual Dinner " ended.

A paper read at the 173d Meeting of the American Institute of Electrical Engineers, New York, February 27th, 1903.

RAILWAY TRAIN LIGHTING.

INTRODUCTION BY PRESIDENT SCOTT.

A gentleman whose whitened hair indicated that he has passed his three-score years and ten, recently gave me a most interesting account of his wedding journey some fifty years ago from Western Pennsylvania to Philadelphia. It was a story of travel on stage coaches and canal boats for nearly a week. The particularly impressive point was the change which has taken place in the mode of travel, not only in speed but in comfort and convenience. We take it as a matter of course that our trains are not only to be comfortable and convenient in their various appointments, but that they are to be replete with the luxuries of the drawing-room and the parlor, the dining room and the sleeping apartment. Those of us who are in early or middle life may know nothing of the stage coach, but we can easily recall some of the earlier conditions of train equipment, for it has been only a few years since three or four oil lamps which did little more than make visible the outlines of the interior of a car, were replaced by systems of gas lighting.

The electric light is in many respects the ideal light for train illumination. The light is brilliant, it may be generously distributed in small units, it contributes little to the heating and nothing to the vitiation of the air, it is under easy control and in emergency or accident there is not the liability to cause fires that is possessed by oil or gas.

The electric problem is in one sense a very simple one—a small number of lamps such as are found in an ordinary residence or office is to be supplied by current. On the other hand, the problem of supplying the necessary current to these lamps is a pecu-

liarly intricate and difficult one. The only practical source of current is a generator from which the current must come either directly or through a storage battery. The simplest equipment is probably the storage battery located upon each car, which is charged or replaced at stations or lay-over points. The arrangement is comparable to the electric automobile except that the demands upon the train battery are not subject to the severe and irregular service which falls to the lot of the automobile battery. The arrangements for the charging of the batteries are apt to be, to say the least, somewhat inconvenient and expensive and the battery itself may be of a considerable weight, if it is to be in service for long periods without recharging.

If an engine-driven generator be placed upon the train, it may receive steam from the locomotive, or the engine may have its own fuel supply. Dependence upon steam supply from a locomotive is not easily practicable if a continuous supply of current is to be obtained, nor does a generating plant upon a single car of a train, even if it have its own fuel supply, allow the ready shifting of cars and making up of trains, unless there be a storage battery auxiliary. A generating unit upon each car is apt to be expensive and add to the general complication of the equipment.

A generator driven from the car axle by the motion of the train involves the operation of an essentially constant voltage machine from a variable speed drive having wide and irregular variations, as well as periods of rest. The problem, therefore, is a most difficult one as the supplying of a small amount of energy to a few lamps cannot by our present methods of converting energy be conveniently effected from any available source.

The fact that current for train lighting is obtained by one means or another demonstrates the facility which inventors and engineers possess for overcoming difficult problems, and it also emphasizes the value attached to electric light. The fundamental difficulty lies in the fact that the available methods of transforming energy and of storing electrical energy are so cumbersome and inadequate. The very difficulties are an appeal for new methods, for simple and efficient methods of transforming energy from its abundant and convenient sources into the desired form of electrical current. The motion energy of the train is almost infinite compared with the meagre amount of energy required for a few glow lamps, but apparatus for transforming, regulating and storing that energy is complicated and costly. The chemical energy contained in a few pounds of coal would be

ample for the evening lighting of a whole train, could it be efficiently transformed into electrical energy. An ice machine by which the heat in a pail of water could be abstracted in the form of electrical energy, would illuminate a car during a long journey as a lump of ice was being frozen.

The problem of train lighting is of general interest, aside from the specific interest which there is in following the details of systems by which the illumination may now be accomplished. It indicates the admirable adaptation of electricity through the incandescent lamp for contributing to the safety, the convenience and the luxury of travel. It presents most peculiar and exacting conditions with respect to the supplying of current which do not render our present sources of current readily applicable. And it further shows the inadequacy and the limitations of our present methods of transforming energy and the possibilities which await scientific investigation, discovery and invention in unexplored fields.

A paper presented at the 173d Meeting of the American Institute of Electrical Engineers, New York, February 27th, 1903

AN ELECTRIC CAR LIGHTING SYSTEM.

BY W. L. BLISS.

A description of an axle-driven electric car lighting system in which the generator is located on the truck frame, the armature being rotated by means of a single reduction gearing. Explanation of the mechanical construction of the generating apparatus and the method of controlling the electrical energy under all conditions of railway service.

In presenting this paper, the author assumes that the members of the INSTITUTE are generally familiar with the subject of train lighting from the axle, and that no allusion to the previous state of the art, or the many failures and disappointments along this line of engineering is necessary or desirable. The admirable papers of Brown, Bauer, Blodgett and others have familiarized the members of the INSTITUTE with the work that has been done in the past and the degree of success that has been attained. It is with this thought in mind that the author will present for your consideration a modern method of train lighting from the axle that is reliable in its operation, and which has passed beyond the experimental to the commercial stage, and is becoming standard railway equipment.

This system consists essentially of the following elements:

1.—A dynamo electric machine or generator located on the car, or, as is the common practice in this country, directly on the truck frame, and so arranged that its armature is caused to rotate by means of a mechanical connection with the axle.

2.—Translating devices within the car, consisting in general of incandescent lamps and fan motors, and which utilize the electrical energy developed in the generator.

3.—A storage battery carried on the car, whose special function is to supply the electrical energy necessary to operate the lamps whenever the armature of the generator revolves at a speed too low to render the same operative, or when the armature ceases to rotate, which condition is obviously attained when the car is at rest.

4.—Auxiliary automatic apparatus, which, acting in conjunction with the above, will render the operation of the entire system automatic, safe and reliable.

The Problem.

In attempting to attain the results indicated above, a multitude of difficulties present themselves which may be classified into two primary groups: (*a*) those which are purely mechanical and are concerned with the motive power, and which must be overcome before the generator can be operated successfully; and (*b*) those which appertain to the control of the electrical energy after it is developed and which are principally of an electrical nature, although involving no small application of mechanics.

The difficulties under group (*a*) arise from the peculiar character of the source of power, the location of the generator and the conditions under which the latter must operate.

As the generator in this system is located on the truck frame there must first be provided a machine mounting, and axle connection which shall withstand the injury and abuse coincident with the most exposed position in which a piece of electrical apparatus can be placed. Secondly, there must be provided an axle connection which shall not necessitate any change in the manufacture of standard railway axles. Such axles are rough, tapered and out of true, and no connection which contemplates the use of keys, set-screws, etc., or which requires turning, truening or machining the axle in any way will be permitted by railway officials. The reasons for this are obvious and require no further comment. (See Fig. 1.)

Method of Driving.

In this system the generator and driving mechanism are modeled somewhat on the lines of the modern street railway motor, such modifications and additions being introduced as to adapt the apparatus to the special work in hand. A single reduction, gear-driven generator has been adopted, but, unlike the ordinary street-car motor, the entire weight of the machine is carried on the truck frame, it not being possible to journal on the axle, for the latter, as previously indicated, is not, nor will present railway practice permit it to be suitably prepared.

Instead of journaling the axle in bearings attached to the frame of generator, two large brackets are carried out from the frame

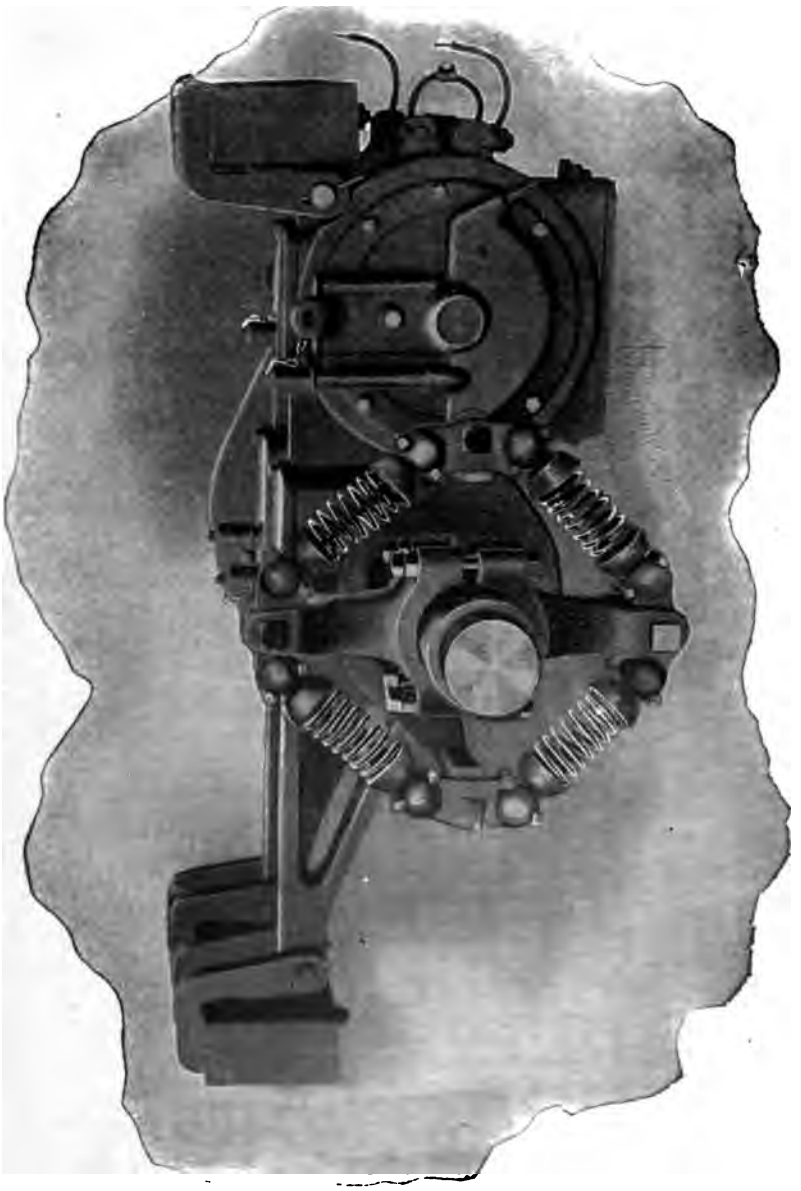


FIG. 1.

or casing of the generator and are adapted to receive and support a hollow shaft, which runs on roller bearings, and upon which the

split gear which meshes with the armature pinion is mounted. The hollow shaft, as well as the brackets, is divided longitudinally, in order to permit assembling on the car truck. The car axle extends through the hollow shaft, a clearance of nearly two inches all around the axle, and between it and the hollow shaft being provided. (See Fig. 2.)

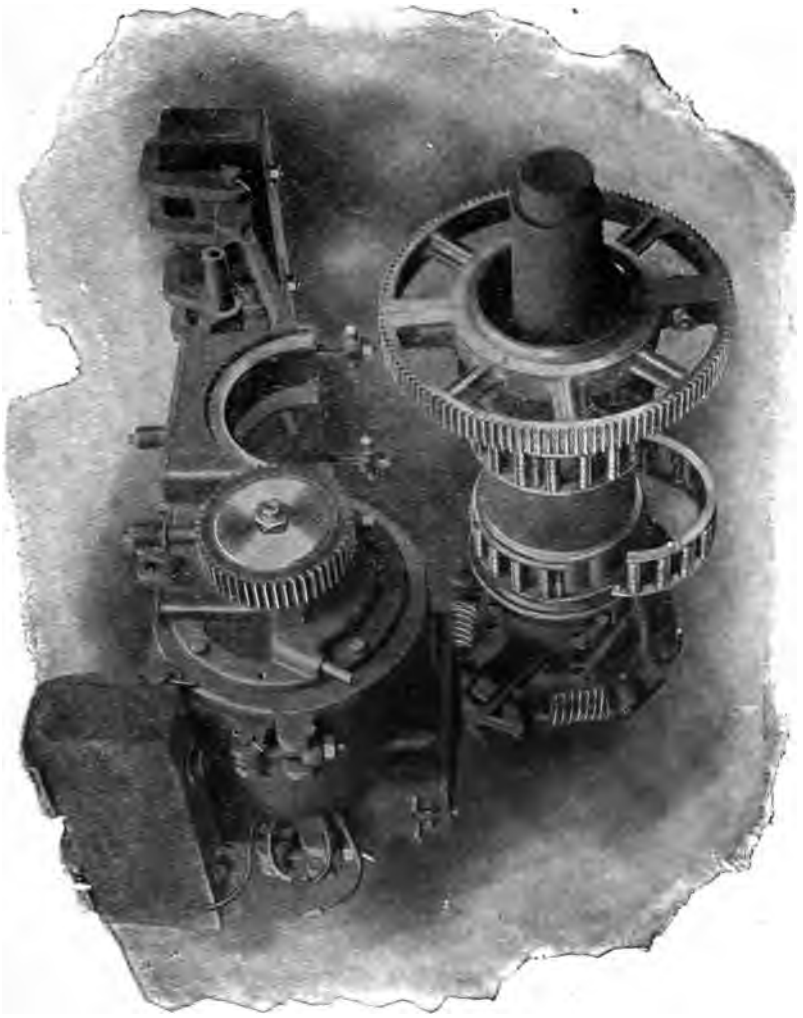


FIG. 2.

This clearance permits the axle to take all manner of motions and positions (within certain limits), with reference to the hollow shaft. Only one component of the axle's motion is transmitted to the hollow shaft, this component being that of rotation. All other motions, the horizontal, vertical and end shake, being pro-

vided for in a positive though flexible connection between the axle and the hollow shaft. This consists of a two-armed dog clamped on by four bolts securely upon the axle, and four specially constructed driving-springs which are attached by means of ball-and-socket fastenings to the two ends of the dog, and to the two arms of the hollow shaft.

The driving-springs are of the " keg " or helical type, wound with tapered ends, and are mounted in shallow cups, through which are screwed ball-ended bolts, which form a part of the ball-and-socket fastening referred to. Inside the springs, the bolts are threaded and provided with nuts and conical washers which fit the inside of the tapered ends of the springs. The nuts are set up with a spanner wrench and locked with spring cotters. An opening is cast in each end of the dog, through the jaws or sides of which a bolt passes, and in this opening and secured by the bolt is a socket-casting split in a vertical plane. The casting projects on each side of the dog and is hollowed out at each end like a bullet mould, thus forming two spherical seats or sockets, into which the ball-ended bolts of the driving-springs fit. The two halves of this socket-casting are fastened together by four $\frac{3}{8}''$ bolts, to prevent their opening and allowing the balls to wear on the joint between them. Similar socket-castings are secured to the two arms or cranks of the hollow shaft by means of bolts or studs which act as crank-pins. All these castings and fittings are interchangeable. Each driving-spring is connected by means of the ball-ended bolts to a socket-casting on the dog, and one on the hollow-shaft arm. The springs are, initially, neither in compression nor extension, which feature greatly facilitates assembling. The ball-and-socket joints not only admit of the springs assuming all possible angles and positions, but enable them to act either in compression or tension while driving. Two diametrically opposite springs are in compression, while the other pair are in tension, and *vice versa*, depending on the direction of rotation of the axle and hollow shaft. (See Fig. 3.)

The dog need not run true, and no special care need be exercised in mounting it on the axle, it being quite as effective when not so true as when nicely adjusted. The dog is made of malleable iron and cast to fit the taper of the axle. There is a positive advantage in not carrying any of the weight of the generator on the car axle. Supported as the generator is, entirely on the truck frame, it is free from the shock, vibration and pounding which would be communicated to it were it journaled on the axle, as in a street

railway motor. It is very easy with this construction to put the generator out of operation by simply taking the dog off the axle. But the greatest advantage which results from this construction is the absence of necessity for trueing up anything in installing the machine. An approximate centering of the axle in the hollow shaft, and the coarsest kind of work in mounting the dog on the axle, are all that are necessary. All the trueing and lining up are done in the shop, and no knowledge of machine work is required of those who install the machine.

All parts of the mechanism which require it are thoroughly

Fig. 3.

encased or otherwise protected. Automatic and profuse lubrication of the shaft bearings is provided. A cut steel gear on the hollow shaft drives a fibre pinion on the armature shaft. In consequence, these are run dry without lubrication of any kind, which conduces much to the cleanliness of the apparatus. See Fig. 4.

The Generator.

The generator is of the ironclad type, having four internal radial salient poles. The poles are placed at an angle of 45°, with the horizontal, two poles being in the upper, and two in the lower half of the generator, which is divided longitudinally in a

horizontal plane. The casing which forms the yoke of the fields, is extended parallel with the axis of the shaft and is then turned in at right angles thus forming ends, so to speak. These ends are

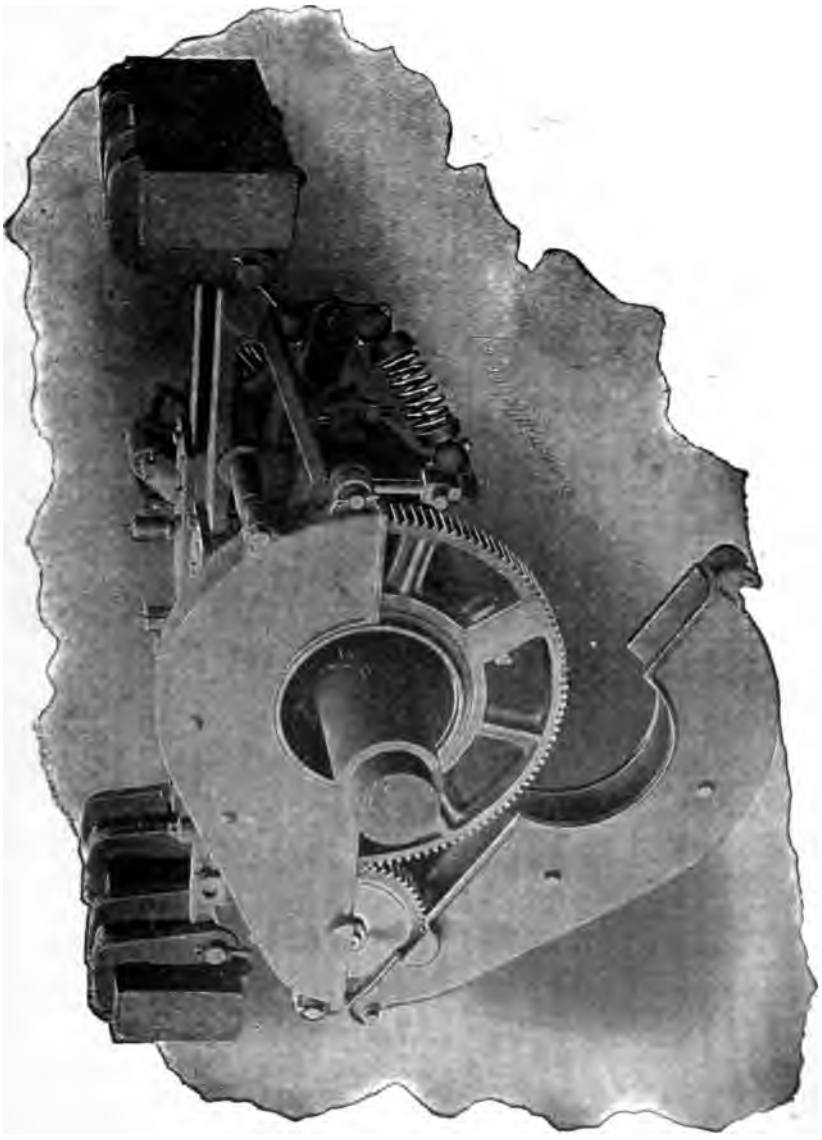


FIG. 4.

bored out and have fitted into them round head-like castings which hold the armature-shaft bearings and oil-wells. When these heads are in place, the generator is almost hermetically

sealed, and is absolutely dust and water proof. Suitable hand-holes or doors are provided in the generator casing for purposes of inspection, etc. The two heads which carry the armature bearings are each held in place by four bolts, two of which are tapped into the upper half of the generator casing and two into

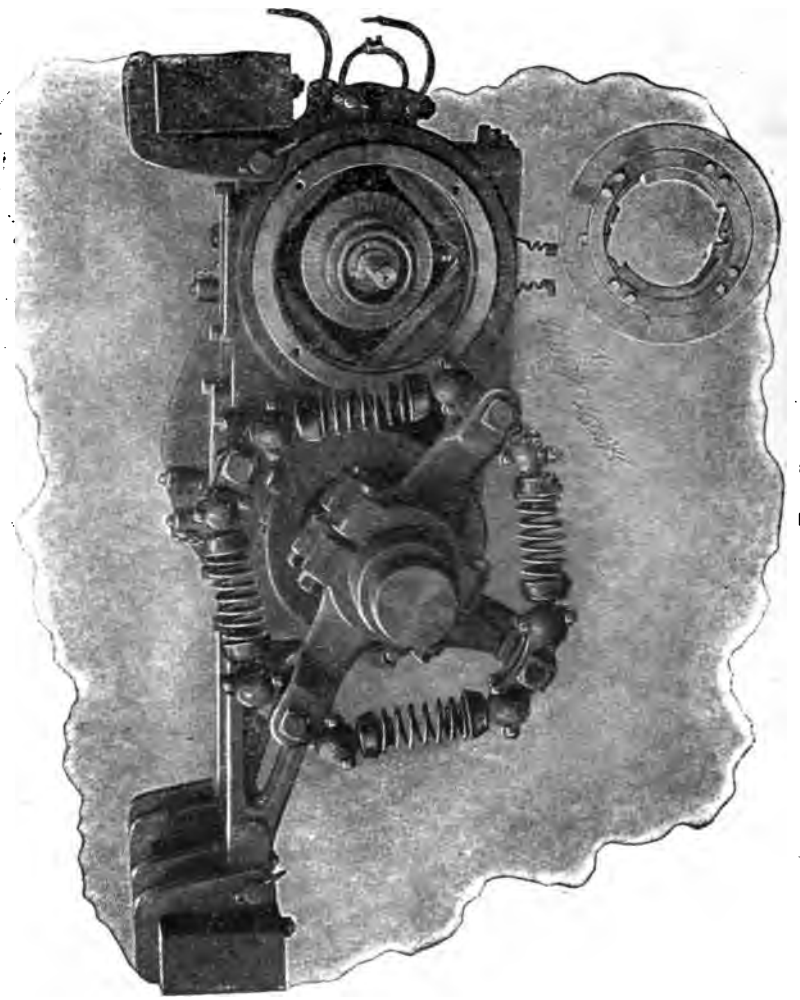


FIG. 5.

the lower. By this construction the lower half of the generator may be removed, leaving the armature in the upper half, or the armature may be removed with the lower half. The heads being nicely fitted to the casing, ensure the perfect alignment of the armature shaft, no steady pins or other trueing devices being

required. By removing the head-casting at the commutator end of the generator, and detaching the flexible cables from their respective brush-holders, the entire brush mechanism, to be described later on, may be removed without disturbing any of the working parts. See Fig. 5.

The armature is of the 4-pole drum type, having a two-circuit singly re-entrant drum-winding of the straight-cut or barrel type. The coils are wound on formers and afterward placed on the armature, thus providing a perfectly balanced winding both

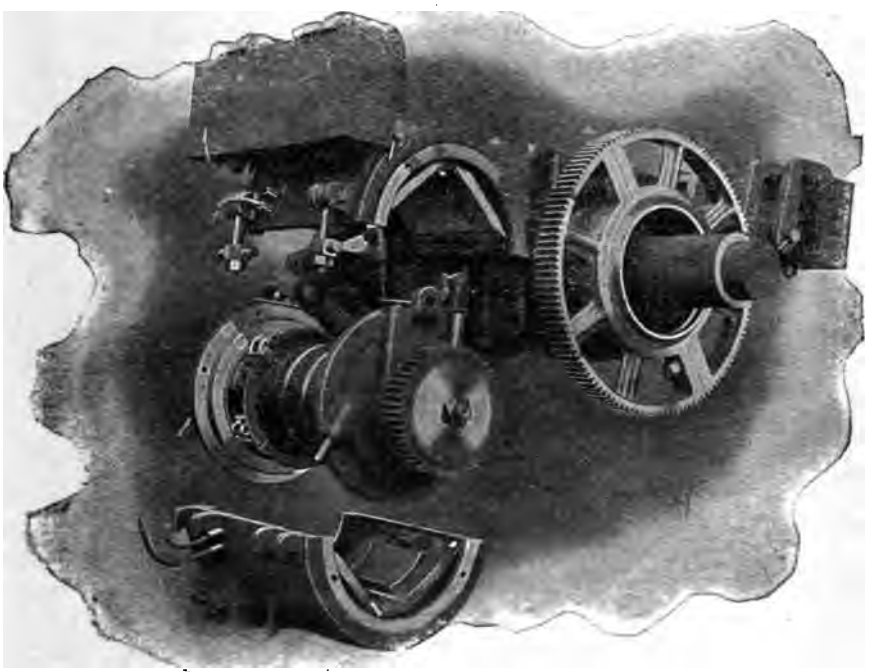


FIG. 6.

electrically and mechanically. The core of the armature consists of the usual annular stampings, slotted to receive the coils, and mounted on a ventilated spider. The central portion of the spider forms a sleeve which is extended at one end to support the commutator. The sleeve is bored out to take the armature shaft, which is suitably keyed and otherwise secured. This arrangement permits the armature and commutator to be quickly taken off the shaft without disturbing the windings, thus affording a ready means for making repairs either to the shaft or to the

armature itself. The construction of the armature, shaft and commutator is extremely substantial. All the running parts are heavily proportioned, and are designed to resist the heaviest shocks and stresses. The generator is connected as a plain shunt-wound machine and is self-exciting. Hence, there is but a single winding on the field, each pole being excited by one coil. See Fig. 6.

The armature winding, being of the two-circuit type, requires but a single pair of brushes to take the current from the commutator, but, for purposes hereinafter explained, two pairs of brushes are employed.

Generation and Control of the Current.

The problems under group (*b*), as previously stated, are principally of an electrical nature. Being provided with a generator driven by the car axle which will supply the required electrical energy to operate the lamps and charge the storage battery, there are four conditions which must be electrically and mechanically provided for, and the operations they entail automatically performed, before the system can be declared operative.

The Pole Changer and Automatic Brush Mechanism.

First.—Provision must be made for the fact, that the direction of travel of the car will be reversed, and hence the direction of rotation of the armature of the generator will suffer a reversal. This would render a self-excited generator inoperative, or would cause a reversal in the polarity of the brushes or terminals of a separately excited machine. It being highly improper to attempt to charge the storage battery with a reversed current, and for other reasons, means must be provided whereby the polarity of the generator terminals is preserved, no matter which way the car may chance to travel. In this system, the polarity of the terminals is preserved in the following manner: The brush-holders are mounted on a carrier, which is supported on anti-friction bearings, which enable it to rotate freely within the casing of the generator. The friction between the brushes and the commutator is sufficient to cause the former, and with them the carrier, to be dragged around as the commutator revolves. The angular motion of the carrier is arrested by means of a stop. When the armature revolves in a right-hand direction, the brushes and carrier are rotated to the right and arrested by the stop in the correct position for commutation. When the armature revolves in a left-hand direction, the brushes and carrier are rotated to the left into a position also correct for commuta-

tion, but a position such that the polarity of the brushes would have been reversed, had not a reversal of rotation in the armature taken place simultaneously. But the rotation of the armature having been reversed, and also the position of the brushes, the actual polarity of the latter is preserved. It will be apparent that the angular motion of the brush carrier need be but 90° in a four-pole generator, such as is employed in this system.

The stop which arrests the motion of the carrier is removable, in order that, for inspection purposes and the renewal of brushes, the carrier may be turned completely around, and all the brushes and holders brought opposite the hand-holes in the generator casing.

As before mentioned, a single pair of brushes would suffice to take the current from the commutator, but by using four brushes, or two pairs, a shorter commutator is possible, a more symmetrical disposition of the brushes is secured, and the adequate friction between the brushes and the commutator is obtained, without undue pressure on a single brush. The brushes of similar polarity are connected together in the usual manner, while flexible cables, which are readily detachable, convey the current from the brushes to the stationary terminals of the generator. Thus it will be seen that in this system the preservation of the polarity of the brushes is secured mechanically, and yet no contacts, switch-blades or other devices, which break or interfere with the continuity of the circuit, are employed. The friction between the brushes and the commutator cannot be avoided, and in this system is utilized to advantage.

The Automatic Generator Switch.

Second.—It is necessary to provide an automatic switch which will complete the circuit between the generator and the storage battery whenever the speed of the former, and consequently its voltage, is equal to or greater than that of the battery. On the other hand, this switch must likewise break that circuit whenever the voltage of the generator is less than that of the storage battery, by virtue of a reduced or zero speed. The object of this is apparent. The automatic generator switch opens and closes the circuit between the generator and the storage battery electrically, and is controlled directly by the generator voltage. It consists of a rectangular iron frame, which forms the magnetic circuit of the solenoid and supports the insulated contacts. Within the frame are two concentric coils, constituting the solenoid. They are made entirely separate, to facilitate con-

struction and repairs, and are held in place by a central tube. The inside, or lifting coil, is wound with fine wire, and is connected as a shunt across the terminals of the generator. The outside, or releasing coil, is wound with heavy wire and connected in series with the generator and storage battery. Within the central tube, and free to work in a vertical direction, is a soft-iron plunger, attached to and insulated from which is a laminated metal brush. When the generator develops its normal voltage of 64 volts, the fine wire or lifting coil will raise the plunger, thus causing the metal brush to make connection between two metallic contacts. If the generator voltage is increased, current will flow from the same through the contacts, brush, and series coil, and through the battery. the series coil being wound in such a direction that this current aids the shunt coil in holding up the plunger and brush, maintaining a better contact for increasing current. When, however, the voltage of the generator becomes less than that of the battery, current will flow from the battery in a reverse direction through the series coil and generator and oppose the action of the shunt coil. The weight of the plunger and brush is now sufficient to cause the opening of the switch by gravity. No springs are used to secure the adjustment. Adjustment is made by varying the length of the air-gap, and when once made is permanent. Carbon contacts, on which the final break takes place, protect the metallic parts against injury by arcing. See Fig. 7.

Upon the top of the iron frame of the automatic generator switch is mounted a triple contact, consisting of a three-part segmental socket and a conical plug fitting the same. The plug is raised and lowered by means of a tail-rod attached to the plunger of the switch. When the plunger is down and the generator switch open, the plug connects the three segments together. When the plunger and plug are raised by the lifting coil, the triple contact is broken. The plug is insulated from the tail-rod and a flexible conductor permanently connects the plug with an insulated terminal, also mounted on the iron frame. One lead of a resistance coil, located in the upper part of the switch-box, is connected to this insulated terminal, and the other lead is connected to the front segment of the triple contact. The negative lead of the generator is also connected to this segment. The leads of the lifting coil are connected, respectively, to the positive of the generator and the terminal to which the flexible conductor is attached. Thus it will be seen that when the plug

establishes the triple contact, it also short-circuits the resistance coil. When the plug is raised, it throws the resistance into series with the lifting coil.

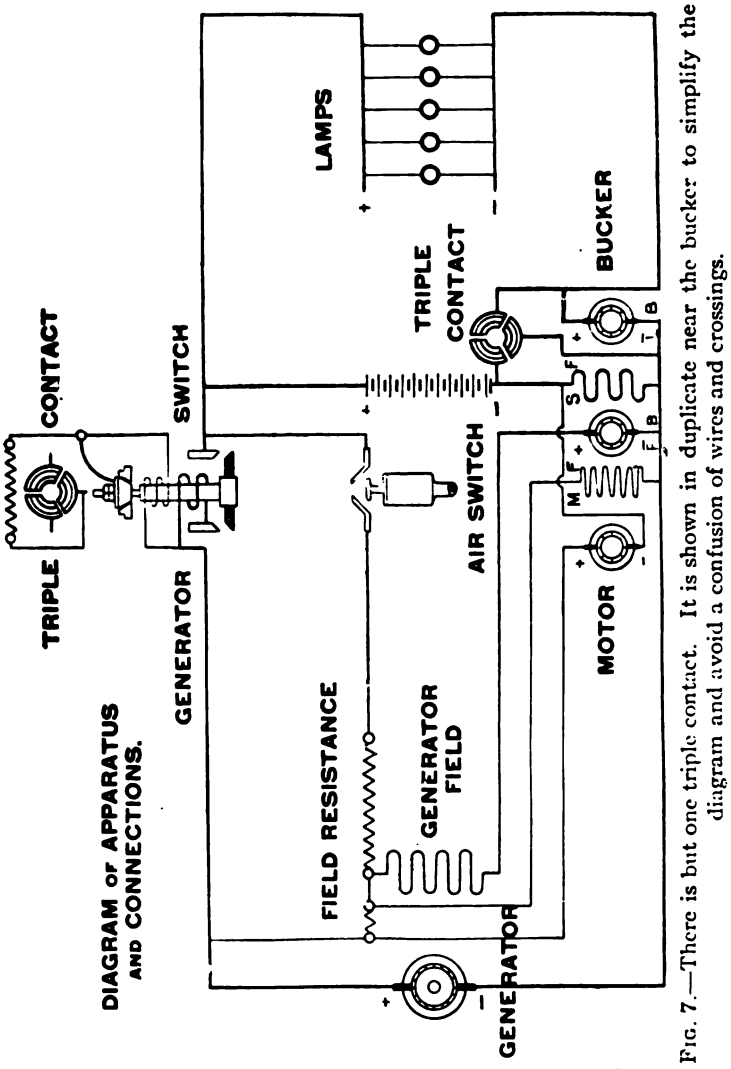


FIG. 7.—There is but one triple contact. It is shown in duplicate near the bucker to simplify the diagram and avoid a confusion of wires and crossings.

The resistance is thrown into series with the lifting coil: (1) To reduce the current and consequent heating in the coil, which would otherwise change its resistance and alter the adjustment of the switch; (2) to reduce the magnetizing effect of the coil, so

that less discharge current will be required in the releasing coil to open the switch, as above explained.

The function of the triple contact is to short-circuit the lamp bucker and series field, to be described later, thus avoiding the drop that would otherwise take place in the lamp circuit when the battery was discharging, and to render the bucker inoperative

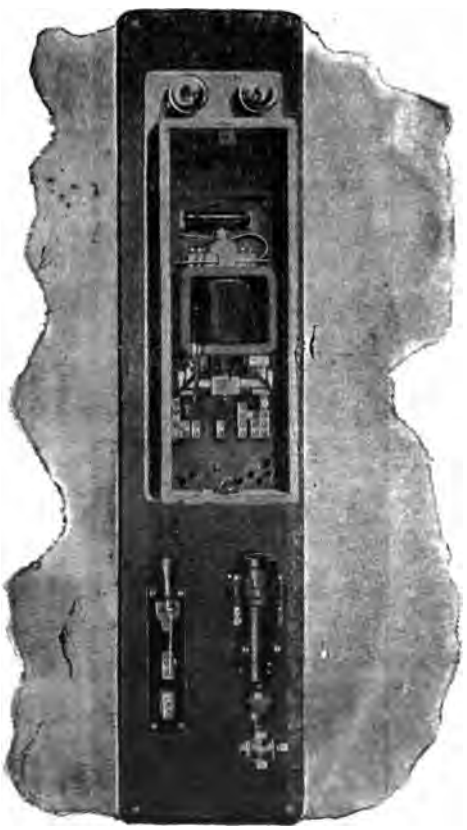


Fig. 8.

at speeds below 20 m.p.h., when the generator switch is open.

At the top of the switch-box are shown two pilot-lamps, connected in series across the generator terminals. The lighting of these lamps affords a visual indication that the generator is in operation.

Fig. 8 represents the switch-box and switches complete The cast-iron cover being removed, exposing the automatic generator

switch, with its triple contact and resistance coil. Below are seen the hand switch and air switch.

REGULATING THE GENERATOR FOR VARYING TRAIN SPEEDS.

Third.—It is desirable to have the generator develop its normal voltage, equal to that of the battery, at as low a speed as possible, consistent with economic design, in order that the electrical energy developed by the generator may be available during as long a proportion of the car's travel as possible. In this system, using 32 cells of battery having a normal voltage of 64 volts, the generator is so designed and so geared to the axle that, when running at 500 r.p.m., corresponding with a train speed of about 20 miles per hour, it generates 64 volts. If, now, the train should increase its speed until it reached about 60 miles per hour, the armature of the generator would be making about 1,500 r.p.m. All other conditions remaining the same, the voltage of the generator would, of course, be proportional to its speed, and hence the voltage at its terminals would rise to about 192 volts. As a matter of fact it will be sufficient to have the generator increase its voltage to 80 volts at maximum speed, as this will be approximately 2.5 volts per cell, which is ample to force the full charging current through the battery. If the generator voltage is not in some way prevented from rising above the predetermined value of 80 volts, great overloading of the generator, batteries and wires will result. In fact, such increase must be positively prevented, and the provision of means therefor constitute one of the distinctive features of this system.

The method of regulation consists in generating, by independent means, a counter e.m.f. in the field circuit of the generator, which increases in proportion to its speed and voltage, and hence reduces the field current of the generator, and prevents excessive output. The details of this arrangement are described under the heading of the bucker and its operation.

CONSTANT LAMP VOLTAGE.

Fourth.—As above pointed out, the fundamental object of the storage battery is to maintain the supply of electrical energy for the lamps whenever the generator is inoperative. Hence it is customary to keep the lighting mains permanently connected to the terminals of the battery. (A hand switch placed in these mains serves to connect the lamps with the battery at will). The lamps are generally operated in parallel, and in this system are 60 or 65 volt lamps. When the battery, consisting of 32 cells, is freshly charged, its voltage is approximately 2 volts per cell,

giving a total voltage of 64 volts across the lamp mains. As the battery is discharged, this voltage will decrease, but should never be allowed to fall below 60 volts. On the other hand, it must never be allowed to exceed 64 volts.

If the train is brought to a speed such that the generator develops, say, 72 volts, sufficient to force about half the charging current through the battery, and the automatic generator switch be closed, the voltage at the terminals of the battery, and hence that impressed on the lamps, is 72 volts. This is an increase of 12½ per cent. in lamp voltage, an obviously excessive variation, while at 80 volts, which is necessary to force the full charging current through the battery, the variation in lamp voltage would be 25 per cent., which would probably be followed by destructive effects. In order that the voltage may remain constant at the lamps, irrespective of the rise of voltage at the battery terminals coincident with charging the same, it is necessary to resort to some form of artificial regulation.

In other words, a variable drop must be taken up in the lamp circuit, either by a variable resistance or rheostat, or by a variable counter e.m.f., to compensate for the rise of voltage at the terminals of the battery. But as the current in the lamp circuit may vary, due to a change in the number of lamps, a rheostat must change its resistance, not only to compensate for the rise in e.m.f. at the terminals of the battery, but also to meet the variation in the number of lamps in use. This requires a double variation of resistance, which, to be automatically performed, is very difficult. Hence a device having no resistance, but capable of developing a variable counter e.m.f., is far preferable; and a low-resistance armature, revolving at constant speed in a field which varies as the rise in e.m.f. at the terminals of the battery, is independent of the variation in the lamp current due to changes in the number of lamps, and constitutes such a device.

All the currents and e.m.f.'s developed in an axle-driven car lighting system are variables, and are functions of the train speed. There is, however, one rectilinear relation that exists among these quantities that can be utilized to produce a constant lamp voltage. It is an observed fact that the current that may be forced through a storage battery is almost directly proportional to the e.m.f. applied at its terminals, less the counter e.m.f. of the battery itself. In other words, the current forced through the battery (charging) is proportional to the increase in e.m.f. at its terminals. This is true over the greater range of the battery's

capacity. As the battery is charged, its counter e.m.f. rises slightly, and hence, when the battery is fully charged, the lamps will be brighter than if the battery were exhausted.

This relation between the charging current and the rise in voltage at the terminals of the battery is utilized in a manner extremely simple, theoretically perfect, and in practice so nearly so, that it requires the use of a good voltmeter to detect the changes in voltage on the lamps, no matter how many be in use or what the speed of the train may be.

THE "BUCKER."

A separate auxiliary and self-contained machine which is called a "bucker," is bolted to the bottom of the car in any convenient place. This machine contains a revolving shaft on which are mounted two armature cores. One of these armatures with its commutator and field, constitutes a plain shunt motor which takes its power from the generator mains and whose sole function is to rotate the shaft. It is obvious that this motor runs only when the generator is in operation. The other armature has two windings and two commutators, and revolves in a field excited by the current flowing through the battery. This double-wound armature, with its two commutators and field, constitutes the "bucker" proper. The motor simply drives it. The winding connected in the lamp circuit is called the "lamp bucker," and the winding connected in the field circuit of the generator the "field bucker." The field of the "bucker" is referred to as the series field, that of the motor as the motor field.

Fig. 9 represents the "bucker" complete. As will be seen, it is entirely enclosed, and hence is dust and water-proof. It is impossible for any one to tamper with it, and it contains no delicate or complicated parts.

Fig. 10 shows the internal construction of the "bucker," it being similar to that of the generator, in being longitudinally divided in a horizontal plane.

The motor and "bucker" armatures are drum-wound for bipolar fields. They are built up of slotted annular punchings, and mounted, together with their commutators, on a sleeve which is fitted and keyed to the shaft. The construction is very similar, to, and possesses all the advantages of that employed in the generator armature previously described. There is no pulley or external mechanical connection to this machine.

The field is of the bipolar, ironclad type. Each armature core revolves between two salient pole-pieces, which are bolted into

the casing, and consist of a pole-shoe and core. Upon each core is placed a heavily taped and painted coil. The pole-pieces are placed in a vertical line, so that one pole and coil for each armature core is in the upper, and one in the lower part of the machine.

The brush-holders are mounted rigidly in the upper half of the machine. Their springs, fingers and cams are interchangeable with those of the generator. In taking off the bottom half of the casing, or in removing the armature, no wire connections need be disturbed, beyond disconnecting the two lower field leads, and the two leads connecting the fields.

The head-castings, containing the armature-shaft bearings, are secured to the casing by four bolts in each, thus permitting the

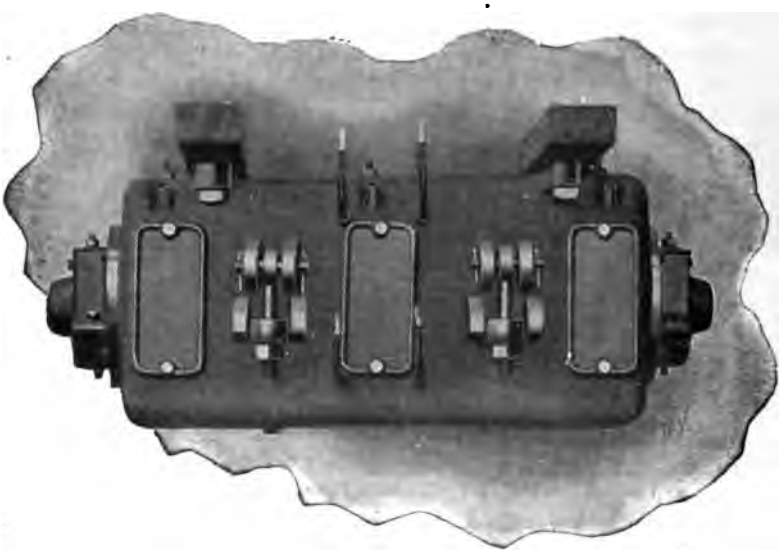


Fig. 9.

lowering of the bottom half of the casing with or without the armature. The armature is shown entirely removed, together with the head-castings and armature-shaft bearings. The separate parts of this machine are light enough to be easily handled, no jacks or lifting devices being necessary. By referring to the cuts, it will be seen that hand-hole covers are provided over each brush-holder, thus affording, by their removal, easy access to all the internal parts.

Operation of the "Bucker."

When no current flows through the battery, none flows through the series field, and hence no c.m.f. is generated in the "bucker"; but

when current flows through this series field e.m.f's are generated in the "bucker," and in almost exact proportion to the strength of the field. (After the closing of the automatic generator switch, the motor runs at almost constant speed, its slight acceleration as the generator voltage rises from 64 to 80 volts, being an advantage, as it compensates for the drooping curve of magnetization in the series field.) See Fig. 7.

No current will flow through the series field under the following conditions:

1st. When the generator is inoperative, automatic generator switch open, and no lamps lighted, *e.g.*, car standing still in day time.

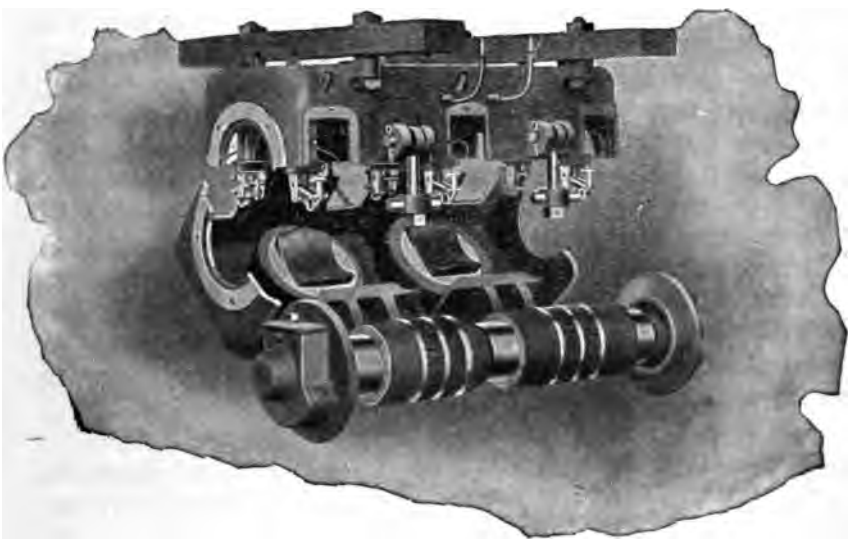


Fig. 10.

2d. When the generator is operative, automatic generator switch closed, no lamps lighted and the generator voltage equal to the battery voltage, *e.g.*, running 20 miles per hour in daytime.

3d. When the generator is operative, automatic generator switch closed, lamps lighted and batteries discharging, carrying all or a portion of the lamp load, *e.g.*, running 20 to 25 miles per hour at night, lamps lighted. Current would, in this case, flow backward through the series field, as the battery is discharging, were it not prevented from so doing.

4th. When the generator is operative, automatic generator

switch closed, lamps lighted, and generator just carrying the lamp load, batteries neither charging nor discharging, *e.g.*, running 25 miles per hour at night, lamps lighted.

Under these conditions, no regulation of generator or lamps is necessary.

Only one condition obtains when regulation is necessary, and that is:

5th. When the generator speed and voltage have risen and the battery is being charged, *e.g.*, running above 25 miles per hour, day or night. Then the voltage at the lamps rises, and it must be kept constant, whether the lamps are lighted or not.

The voltage at the terminals of battery rises about in proportion to the current forced through them. The magnetism of the series field increases in proportion to this current. The e.m.f's of the "bucker" (its speed being nearly constant) increase in proportion to its field magnetism. Hence, the e. m. f's. of the "bucker" increase in proportion to the rise of e.m.f. at the battery terminals. If the winding connected in the lamp circuit be proportioned correctly, its e.m.f. can be made equal at all times to the increase of e.m.f. at the battery, and so if this winding be connected inversely in series with the lamps, it will produce a counter e.m.f. in the lamp circuit always equal to the excess e.m.f. necessary to impress on the batteries to charge them. The result will be a constant lamp voltage, independent of the number of lamps in use, or the speed of the train, since the latter now affects the charging current only.

Regulation of the Generator.

The other winding of the " bucker" is connected inversely in series with the field of the generator, and generates a counter e.m.f. which weakens the field of the latter to such a degree that the e. m. f. of the generator is just sufficient at the maximum train speed to force the maximum predetermined current through the battery and series field. The regulation tends to maintain constant current through the battery and series field at a given train speed. The lamp load is carried by the generator precisely as in the case of a constant potential machine and does not affect the charging current flowing through the battery.

Since the " bucker" receives or absorbs energy from the lamp circuit and the field circuit of the generator, such energy is transformed into mechanical power and tends to revolve the shaft and thus relieve the motor of that work. In fact, when the apparatus is fully loaded, the motor becomes a generator and puts back

into the system about 60 per cent. of the energy consumed by the "bucker" in effecting regulation.

Under (3) no regulation for holding down the lamp voltage or generator output is necessary, but since, under such conditions, the battery would discharge and current would flow from the battery through the lamps, "lamp bucker," and backward through the series field, the polarity of the "bucker" would be reversed, and the latter would become a booster and tend to raise the lamp voltage and increase the generator output by strengthening the field of same. This tendency of the "bucker" to "boost" when the battery discharges through the series-field, while the generator switch is closed and the triple contact open, as already explained, is prevented by causing the current which flows from the generator through the motor to return through the series field in a direction opposite to that of the battery current discharging through the lamps and series-field. This motor current increases with the tendency of the "bucker" to "boost", which tendency is proportional to the lamp load at this time, for the more heavily the "bucker" (now a booster) is loaded the greater the motor current required to drive it. As these two currents cannot flow through the same field at the same time in opposite directions, their resultant, which in this case is their difference, is the current which actually flows; and such resultant can, by proper design, be made approximately zero; or, at least, the tendency to "boost" can be practically eliminated.

Air-Operated Field Switch.

In addition to the difficulties to be overcome to render the electrical operation of the system perfect, there is one other point which requires attention, although not absolutely vital. For the sake of simplicity, a self-excited generator is usually employed, although it is not uncommon to separately excite the field of the generator by means of current from the storage battery. If such current be used to excite said field, provision must be made to discontinue it after the car goes out of service; otherwise, a useless discharge of the battery will take place. It is desirable to provide some form of separate excitation, as the generator may fail to excite or "pick up" at the proper speed through loss of residual magnetism, imperfect contact of brushes, etc.

In this system, the generator remains connected as a self-exciting machine, and eventually furnishes the strong current in its field required to produce 64 volts at the low speed of 20 miles per hour. Separate excitation for the field of the generator, and

also for the field of the motor which drives the " bucker," thus enabling the motor to start readily, is supplied by means of current from the storage battery, which current is limited to a small value by the field resistance. The circuit from the storage battery through the field resistance is controlled by an automatic device called the air switch. This consists of a cylinder, to the lower end of which a branch from the signal pipe of the car is connected. An ordinary gas-cock, included in this branch pipe, serves to cut off the supply of air, so that the cylinder may be opened or disconnected without venting the signal line. Within the cylinder is a cup-shaped piston, to which a rod is attached. The latter extends through the cylinder head and carries an insulated contact disk. The piston is held in its normal position by means of a helical spring surrounding the piston rod, and engaging with the inside of the cup-shaped piston and the under side of the cylinder head. When the piston is forced upward by air pressure, the rim of the cup is pressed against the gasket, which packs the cylinder head, thus sealing the cylinder and preventing escape of air. This construction permits the use of a loose-fitting piston, which ensures freedom from possible sticking. At the same time the contact disk on the piston-rod establishes connection between the two spring contacts mounted upon and insulated from the cylinder head, and which are secured by the same bolts that hold the latter in place. The heads of these bolts form binding-posts for the reception of the circuit wires. A bonnet or hood protects the contact parts. See Fig. 8.

When the locomotive is coupled to the train and the hose couplings are connected, pressure is at once applied to the air-switch and the circuit is closed. When the locomotive is uncoupled, the pressure in the signal pipe rapidly falls, opening the air-switch immediately, or within a few minutes. Reduction of pressure, caused by giving signals, does not open the switch, and even if it did, no harm would result, as the switch may be opened with impunity as soon as the generator has developed a stable voltage of about 15 volts. When the automatic generator switch closes, it short-circuits the air-switch, in addition to its other functions. After the disconnection of the locomotive, the conductors' valve may be used to open all the switches on a train simultaneously, in case the pressure in the signal pipe is retained. The leaks in the hose couplings are sufficient to cause a rapid falling in pressure and a quick opening of the air-switch

A paper read at the 173d meeting of the American Institute of Electrical Engineers, New York, Feb. 27, 1903.

AXLE-LIGHTING.

BY ELMER A. SPERRY.

A historical view of electric train lighting; a statement of some of the problems encountered; a criticism of some of the methods employed in solving these problems, and an announcement concerning a new system of axle-lighting.

The persistence of methods casually considered as "good enough" is well illustrated by a review of the small advances of the past decade in car lighting. When the series of trains known as The Pennsylvania Limited, had then been electrically illuminated throughout for more than five years, an author of ability started his excellent work by denominating this subject a "burning question." This was twelve years ago. Oils and naphtha and their products was the burden of his message, and yet, to-day we are confronted by all too frequent reminders that it has not, as yet, emerged from this class.

That the confines of this "burning question" lamentably is not limited to illumination, is illustrated by the periodic firing of solidly steam-heated trains in state of wreck.

Oil, gas, carbonated-air gas generators and acetylene are employed, some very extensively; some, if not most of them, combustible and inflammable to a superlative degree and necessarily in close proximity to combustible linings and trimmings.

The mass of work that has been done as exhibited by the elaborate details which have been perfected in many of these systems, emphasizes the importance of a perfect system of car and train illumination.

Electricity has been proposed from the very first. When the early platinum filament gave forth its prophecy, its adaptability

to car lighting was at once seen, and a great future was predicted for this form of illumination for trains.

Among its points of superiority, should not be overlooked the fact that it is cleaner, more pleasing than any other, and lends itself more readily to decorative effects. It can be divided into smaller units than any other and can thus be distributed and placed in more advantageous positions; its familiar use as reading lights, or berth lights, serves to illustrate this point. Also the heat emitted is negligible. It is absolutely unaffected by draughts; it maintains its original candle-power better on the whole than any other light, and is less dependent for its existence on the faithful care of the trainmen. Its safety is beyond question. From it no oil can drip, no odor or smoke can be emitted, and there is entire absence of odor in the stations. Many important stations are rendered almost unbearable by the pungent and poisonous odor of compressed gas.

Electrical car lighting in America will attain its majority within the present year. In August, 1882, the Pennsylvania Railroad Company electrically equipped car No. 397 with Faure Accumulators imported from France for the purpose. Not only is this the earliest application of electricity to car lighting in this country, but in fact one of the earliest in the world. Again, it was this same enterprising road that promoted the first installation of the solid electrically illuminated trains or series of trains, the Pennsylvania Limited, between New York and Chicago. These equipments were installed in the middle eighties and are still in continuous service; all are direct-connected sets in the baggage compartment, supplying the lamps, together with batteries under each car.

Meanwhile, English railways were active in the same line, their first installations being axle-driven. The London, Brighton and South Coast Railway, in 1883, put on its first axle-driven equipment, which furnished a few lamps throughout the entire train, not many more than was supplied to a single Pullman car in this country. In 1885 the Mechanical Superintendent of this road, Mr. Stroudley, described this system in detail before the Institution of Civil Engineers in London.

This was quickly followed by the Great Northern and the Midland roads, each of which in 1886 developed similar equipment, one using the old Brush dynamo, both dynamo and batteries in the "guard's van," similar in this particular to the Brighton and South Coast road. The difficulty of leaving the cars in total darkness on breaking up the train was later obviated

in the Midland equipment by distributing the batteries under each car, as was practised in the Pullman equipment in this country. Many of these early installations are still in service.

The writer has recently had opportunity personally to inspect some of the oldest of these equipments, and can testify to their marvelous state of preservation, especially considering the service they have seen. It should be stated in passing that these old equipments are of extreme value in throwing light upon the one great unknown factor in ascertaining the cost of operation; namely, deterioration. The experience of these roads allows us to establish a sinking fund which it is believed can be depended upon to take care of this portion of the cost of operation the other factors being more easily determined.

In passing from the old to the new, it is interesting to note the transformation which we have all noted in the new Manhattan Elevated cars in New York City, which have been electrically equipped. Nothing could better illustrate the comparative merits in point both of candle power and practical "visual units," and of distribution, than the marked contrast between this system and that of the old steam-hauled trains, both of which recently could have been seen constantly passing in the busy hours.

In calculating the electrical power consumption of a car illuminated in a highly satisfactory manner, one is struck with the smallness of the amount required for maintaining the lights. This, when properly adjusted, is found to sink into insignificance as compared with the power required to haul the train, or the particular portion of such power represented in the individual car.

In our modern service the locomotive represents, really, a power station of no mean dimensions, developing, as it does, from one thousand to fourteen hundred horse power and even, at times, a power in excess of this amount. The illumination of the entire train represents not far from one per cent. of this, and with a proper combination of generating units and accumulators, considerably less. In view of modern practice, in other lines, it is found that even with a light battery a generator may be employed during a part only of the day period and thus reduce considerably the maximum power required at any one time, say at the time of the heaviest load. Thus, as a part of every train, there is at hand a power station of large dimensions from which should be drawn the insignificant amount of energy required for illuminating purposes, if the equipment is properly suited to the conditions.

A perfect system requires that every car shall be entirely independent of every other, and shall maintain its lights perfectly after the train is broken up. Many efforts have been made to perfect devices to accomplish this purpose, and they operate more or less successfully. It was my privilege to be called upon recently to investigate the systems that have been offered, with a view to ascertaining the practicability, the reliability, the closeness of regulation and other features of their operation. Much ingenuity and some good engineering is displayed in and about these systems. A criticism might be made that some of the engineering has evidently been done by the electrician rather than by the trained engineer. Some systems employ belt drives as a means of mechanically coupling the generator to the axle. Some of our present fast trains that are thus equipped have come through repeatedly with every belt on the train gone. Again, in some of these equipments, the generator is mounted on the car body with no means of coördinating its lines with the constantly changing alignment of the axle within the swivelling truck. Some are mounted upon the trucks themselves, but so hung that the truck-springs over the axle boxes are required to be re-inforced upon this end of the truck, owing to the overloaded condition thus imposed. In one of these equipments hand regulation is in a large measure depended upon, causing the reliability of the system to turn on the faithfulness and intelligence of the trainmen.

It is certain that the system of the future must be one that is thoroughly automatic throughout, especially in view of the modern trend and perfection of electrical and mechanical appliances. Systems employing slip frictional driving devices for regulation, are open to serious objection in point of power absorption. This problem, at best, is a difficult one. The generator is asked to take on its load at say twenty miles an hour and to continue while the car often reaches a speed of eighty miles per hour. There are instances where the generator is expected to assume its load at even lower speeds, as at fifteen or seventeen miles per hour. This gives a speed variation of four or five to one. It is manifestly undesirable to operate a generator that is large enough to carry its entire load say at 500 r.p.m. at a speed five times as great. Not only does the serious matter of commutation arise, but also a complication of other electric difficulties. Mechanically, it is difficult to build and guarantee a machine under these conditions. Thus it is that slipping

friction devices have been suggested that they may intervene and save the generator. The peripheral velocity in this case, however, has increased four or five times while constantly delivering the large torque strain that was required at the *lowest* speed limit. The other three-fourths or four-fifths of the power, which is positively developed and delivered under these conditions, passes into heat which has to be dissipated, often proving a serious problem, burning and destroying the belts, and other frictional devices employed.

Such waste as this should certainly be avoided, notwithstanding the large capacity of the source of supply. Again, other systems introduce commutating difficulties at the higher speeds. A generator required to assume its load at say sixteen miles per hour must commutate the same load at four and one-half to five times this speed. An increase of heating results from the increase in speed of rotation, arising from hysteresis and other core losses in the armature.

A system has been devised whereby the excess of current developed is neutralized by an elaborate mechanism, which is required to be maintained and operated constantly from the battery circuit and requiring power whenever the equipment is in service. It would seem, from an engineering standpoint, that it would be far better not to call upon the generator for either excessive currents requiring dissipation or upon the car and axle for any more power than is actually required for economically handling the service proposed, and further, not even upon the generator for more speed of rotation than is actually necessary to maintain its load or potentials perfectly constant under the varying conditions.

Another important feature, and one which must always be reckoned with primarily in the car lighting system is perfect and constant control. Here a number of factors are encountered which must be so dealt with as to overcome entirely other influences. Among these are the reversal in direction of rotation, the irregularity and spasmodic magnitude of the variation in speed, the variation in the charging and the discharging e.m.f. of the battery, the jar and tremor of the car or truck on which the apparatus is mounted, and the variation in the load or number of lamps in the circuit.

All that have ridden on cars with axle-driven equipments have noted to what degree this matter of regulation is carried out. Fairly good regulation is not good enough for the lighting of com-

partments under constant use and criticism of the changing public. A dimming light will disgust and a brightening light will surprise a passenger who can always be counted upon as overhasty in judgment and hypercritical. It is perfectly apparent that to compass perfect regulation ponderable masses must be employed and controlled with great precision to keep pace with the erratic changes in speed. To accomplish this it is apparent that the control of such devices and masses cannot be attempted directly by the slight changes in the voltage at command, though they must be perfectly responsive to such changes. Devices that cannot be considered as delicate or be criticised as being other than practical, and which operate within one-half of one per cent. have been found efficient and reliable for control under these conditions.

Announcement is hereby made of the design of a new system of axle lighting. With these regulating devices we have now had six or eight years of experience in continuous and heavy service and the features of its operation have become familiar and its reliability established. The sensitive moving part may be statically balanced, freeing them entirely from any response to the vibrations, jerk and jar of the car and rendering them entirely independent thereof. This device may be relied upon thoroughly to regulate not only the potential as delivered to the lighting circuit under varying conditions of load and battery pressure, but also to handle the generator under all possible conditions of speed variation, reversal and change of load. Furthermore, it has been found that a number of valuable features, having an important bearing on this particular subject, and which have never before been introduced as factors, may be employed with perfect success with this system of control and regulation. Not the least of these is a *constant speed generator* the use of which cuts down the torque delivery from the axle and thus the power absorbed from the axle, in exact accord with the demand for electricity at the time from the generator. When the battery is nearly charged, this current should be largely reduced, and its e.m.f. slightly and gradually increased. Any device which will take from a moving train only the power that is at that instant required to be developed and as the demand falls off will release all overplus of power to the train is certainly desirable if not positively necessary to the success of the coming train-lighting equipment. Especially is this true in view of the fact that by this device a large amount of power now wasted is

not only saved but left available for traction purposes to the locomotive, which is already taxed to its utmost to meet the modern demand for high speeds of heavy equipment. Moreover by this system the weight of battery and generators may be reduced, and the whole system rendered simple in the extreme. Nothing is found necessary to the installation inside the car except the ordinary switch-panel for controlling the lamps of the car. In some instances, such as private and wild-cat cars, it might be advisable to install a voltmeter and ammeter or a combined single instrument which has been designed. Again, in this particular style of equipment, there has been included apparatus designed primarily to reinforce the battery when such a car is required to stand idle on a siding for a considerable length of time. This equipment allows the batteries to be charged from the ordinary 110 volt a.c. as well as d.c. service, Such service is to be had in almost any station whenever the necessity arises, thus furnishing an element of the system not met in equipment heretofore offered. In this instance, the constant speed machine does not require to take on its load at lower than its normal speed. Therefore, it is of minimum weight and size. The generator is suspended interior to the truck and no belts or other than toothed wheels are employed in driving. All parts are housed in dust-proof cases and automatically oiled, and designed to operate for long periods without attention. The generator itself is sealed and can work in snow, wet or dry with equal reliability. The heating factor is low and radiation ample to keep the temperature well within prescribed limits. The air-wash still further reduces the liability to overheat.

The whole question of car lighting turns on practicability,—can the system be made reliable in independent units and at the same time can it compete in point of cost per unit of light? It is true that it does not need to equal the other systems in point of cost per light-unit, owing to the superiority of distribution and its many apparent advantages. It is, therefore, with considerable gratification that the writer is prepared to state that upon this all-important question of cost this system, as a matter of fact, *can compete successfully.*

Taking the items of deterioration and up-keep, as developed by the plants which have been longest in operation and including interest and all essential factors, it can be stated that a *candle-power-hour* can be produced for about 68 per cent. of the cost of

compressed gas, and that such gas, as now used, costs in the neighborhood of 46 per cent. more than an equal illumination in candle-power by the present axle-driven equipment. When calculated in visual units, which includes the distribution factor, compressed gas is in excess of 50 per cent. more expensive than electric illumination, a result upon which it is believed the electrical fraternity should be congratulated, and which should open up a large field for the use of electric apparatus.

A paper read at the 173d Meeting of the American Institute of Electrical Engineers, New York, Feb. 27, 1903.

AN AXLE-LIGHT SYSTEM OF TRAIN LIGHTING.

BY ARTHUR J. FARNSWORTH.

Reasons why axle-systems of electric train lighting have theoretical possibilities of meeting the exacting requirements of the problem better than other systems. A description of an axle-lighting system and its operation.

It is now generally admitted that electricity is destined to be as universally adopted for the lighting of passenger cars on steam railroads as it has been for the interior illumination of buildings. In addition to the well-known advantages it offers as a source of artificial illumination, it is the only light that can be located satisfactorily in any other place than the deck of railway cars, owing to their peculiar construction, and above all, there is the vital argument of safety.

The problem of electrically lighting steam railroad cars naturally presents greater difficulties than are met with in stationary lighting installations. In addition to furnishing the current and maintaining the pressure within satisfactory limits, the system must assure a reliable and continuous lighting service; permit of the cars being assigned to any run on their own or foreign roads; have a negligible effect upon the hauling capacity of the locomotive and compare favorably as to cost of installation and operation with other systems.

For the generation of electricity for train lighting it is possible to make use of power developed in a stationary plant and stored in electric storage batteries; to utilize small independent steam motors, operated by live steam from the locomotive; or to generate the power directly and economically in the large

locomotive cylinders and transmit it through the car axles of the train.

The first two of these can only be made use of in special service confined to certain territory and runs. It is the axle system alone that has an unlimited field of operation. This generating car unit system, therefore, possesses an inherent advantage that should bring it into universal use, provided the apparatus is constructed to fulfil the severe duty imposed upon it. Each car thus equipped contains its own complete electric lighting plant with economical power available and independent of any service and all other equipment.

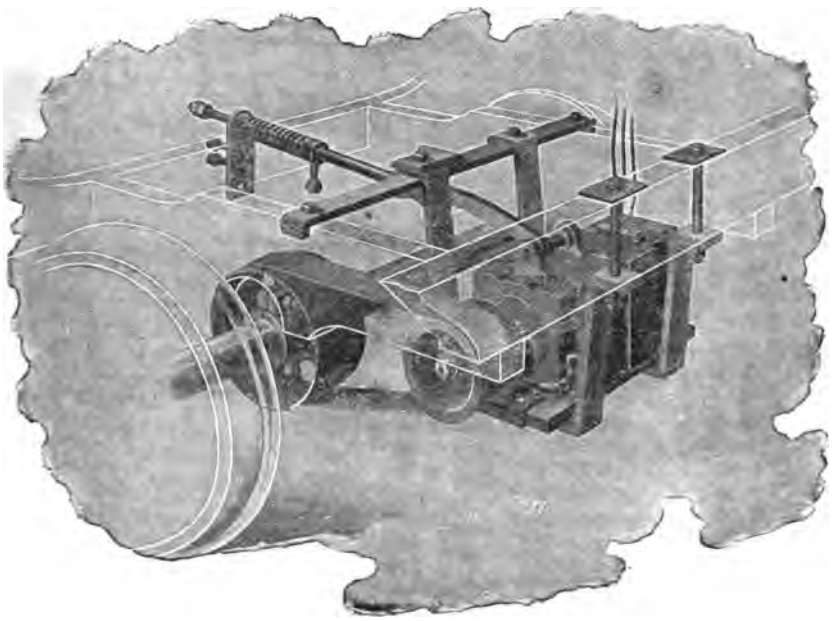


FIG. 1.

The essential requirements of an axle electric lighting system are reliability, automatic operation, close control of voltage at all times, negligible drag upon the locomotive and small total cost of operation.

There are several axle electric lighting systems in use. The main differences between these are in the transmission of power from the revolving car axle to the generator; the means employed to maintain a constant voltage at the lamps at all speeds, and the design of the apparatus, so as to make it as automatic as possible and at the same time so simple that it can be readily understood and taken care of by cheap labor.

The problem of transmitting the power is difficult, for several reasons. The plan of installing the generator in a manner similar to that in which street car motors are mounted is not to-day considered feasible. Railway mechanical officials have adopted the taper axle almost universally, and will not consider any proposition to turn thereon the necessary straight bearings for the generator suspension. Consequently the dynamo must be located independent of the axle, and the drive must provide for a vertical and lateral motion of the latter and a variable distance between centers.

It is also absolutely essential that the drive shall possess the utmost simplicity and be accessible, so that truckmen can easily remove and replace it when changing car wheels. Simple as the matter at first appears, this requirement has proved to be a serious obstacle.

For the transmission of power, a large number of devices have been tried, including gears, sprocket chains, friction pulleys and belts. At the present time belts appear to be in greatest favor, and are used on probably more than 90 per cent. of existing axle lighting devices throughout the world to-day. They have a certain elasticity that is lacking with gears, and vibration and shock are not transmitted by them to any great extent. They do not require lubrication, and if the belt drive is properly designed will run a long time and pull the load.

The second difficult problem is the satisfactory regulation of voltage. As the speed of a railway train is constantly changing, it is necessary to employ means to counteract the tendency to voltage variation. For this purpose various forms of differential winding have been used with some success; and a crude method of accomplishing the result very imperfectly is to depend upon the belt slipping when an abnormal load has been reached.

The principle upon which the system here described is based, is to control the output of the generator and keep it constant by varying the resistance in the field circuit to correspond to the train speed. The regulating mechanism which accomplishes this is thrown into action whenever the generator current varies from normal. It is designed: first, to maintain a constant output of the generator at all train speeds above the "critical speed," or the speed at which it becomes operative; and, secondly, to maintain a constant voltage at the lamps, whether they are being fed from the battery alone, or whether they are connected in multiple with

both the generator and battery at speeds above the critical speed.

The equipment of this system consists essentially of a generator installed upon the truck of the car and driven from the axle by means of a belt; a regulator installed in any convenient location in the interior of the car, and a storage battery hung in a suitable box from the car body.

The generator (Fig. 2) is a bi-polar, laminated field, shunt-wound machine. It is ironclad and provided with self-oiling and self-aligning bearings. It is completely enclosed with dust-tight covers which may be easily removed for purposes of inspection. It is installed on suspension-irons hung on the truck

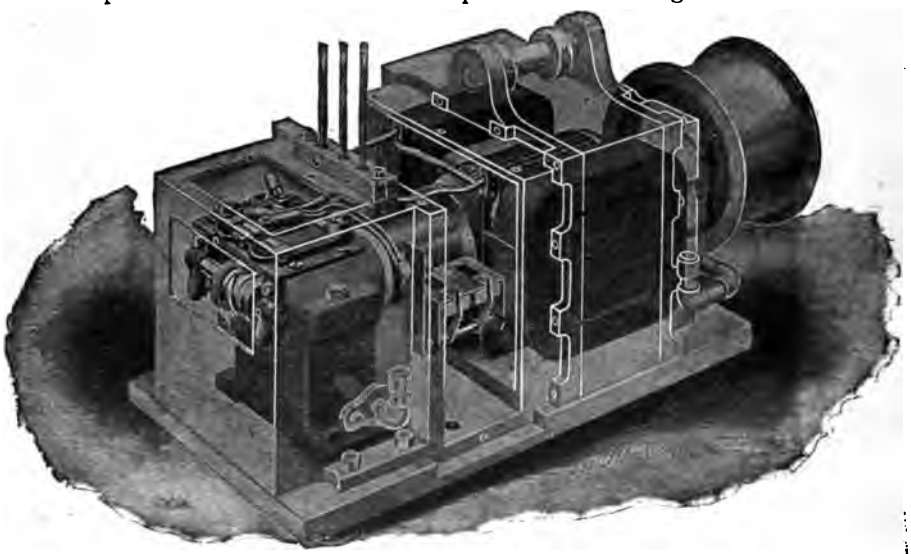


FIG. 2.

timbers, one method being shown in Fig. 1, and is pivoted parallel with the axle, on adjustable pivot-shoes to provide for perfect alignment. A tension rod and spring maintain the proper tension on the belt, the machine being free to swing on its pivot so that any movement of the axle from its normal position will not affect the belt tension. The generator is provided with a flanged crown pulley and on the axle is clamped a flat-face flanged driving pulley, the two being belted together with a rubber belt. The armature shaft carries a worm operating a gear and cylindrical cam, which throws a switch when the direction of rotation of the armature is reversed. The polarity of the generator is thus maintained correct, independent of the direction in which the train is moving.

Carbon brushes are used and the design and proportions are such that if the machine is maintained in good condition it will run cool and sparkless under any ordinary conditions of service. The laminated fields contain a few sheets of hard steel, which retain sufficient residual magnetism to cause the generator to build up its voltage promptly at low speeds. The machine is constructed throughout to meet the severe requirements of railway service and to operate successfully with a minimum amount of care and attention.

The regulator (Fig. 3) contains a solenoid with spring-balanced plunger to control its operation; the generator field rheostat; a small electric motor connected by means of worm gear and ratchet mechanism to the rheostat to operate it; an automatic switch for automatically switching the generator in multiple with the lamps and battery at the critical speed when the speed is rising, and for cutting it out at the same speed when the speed is falling; and a variable lamp resistance operated by the same mechanism that works the field rheostat.

All the operations of the regulator are automatic. The motor is provided with self-oiling bearings, and requires only occasional attention. Re-adjustment of the regulator, when it is once properly set, is seldom necessary.

The battery used is admirably adapted for this class of service, requiring little attention and not subject to rapid depreciation. It is usually proportioned to provide for about ten hours' continuous burning of all the lamps, although in the case of cars subject to long lay-overs this capacity may be increased. Current for the lamps is thus insured under all ordinary circumstances arising in practice.

The automatic switch or cut-out has four bobbins, as shown in the upper right hand corner of Fig. 3. The lower two are wound with fine wire, and the upper two have a winding of heavy wire to carry the main generator current. The lower bobbins always remain connected across the generator terminals through the field fuse and main fuse in series, as shown on the wiring diagram at F, Fig. 4.

As the train accelerates and the generator voltage builds up, current flows through the fine wire winding of the lower coils of the automatic switch and their cores become magnetized in proportion to the rise in voltage. When the voltage of the generator reaches the point where it about equals that of the battery, the magnetic pull of these coils overcomes their weight and that of

the lever and resistance of the opposing spring, and the switch goes in and connects the generator in multiple with the battery and lamps. The main dynamo circuit is then complete from the generator, G, Fig. 4, and fuse, F, through the solenoid, S; through the two coarse wire coils of the " automatic switch," C (in multiple), contacts HJ, through the battery, B, and back to the negative terminal of the generator, G. If the lamp circuits are turned on the current divides part going to the battery and part through the lamp resistance, E, to the lamps, L. As the speed of the train increases above the critical speed, *i.e.* the speed where the cut-out goes in, the generator current increases in proportion until it

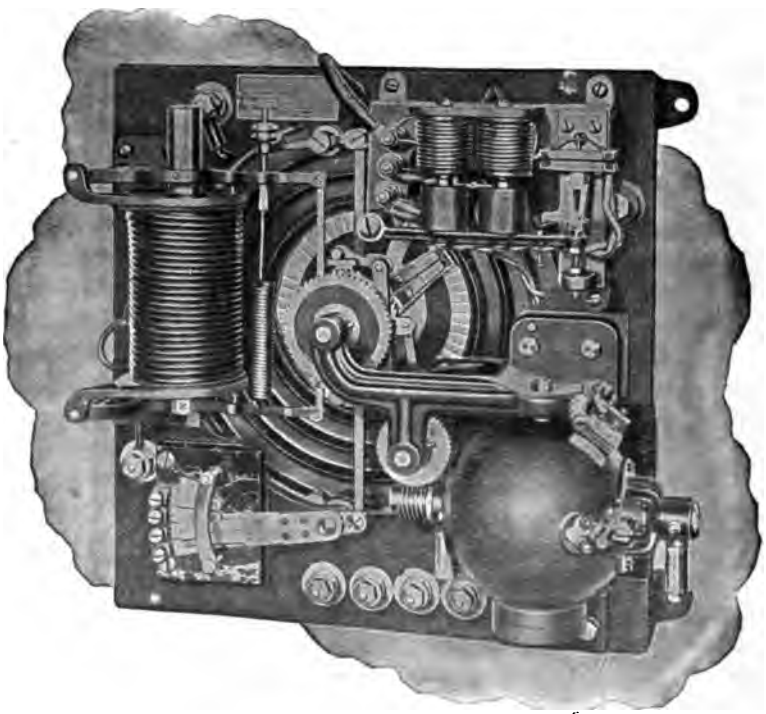


FIG. 3.

reaches the point where the magnetic pull on the solenoid core balances the pull of its opposing spring.

Any further increase of train speed, tending to increase the current generated, will cause the solenoid spring to be over-balanced, throw into gear the ratchet mechanism and move the generator field rheostat arm through one or more contacts until the current is cut down to the proper amount and the solenoid plunger is again in equilibrium. A still further increase of speed

will act in the same manner. A decrease of speed will cause the mechanism to act in a similar manner and cut out resistance from the field circuit of the generator. The generator current is thus maintained nearly constant at all speeds above the critical speed.

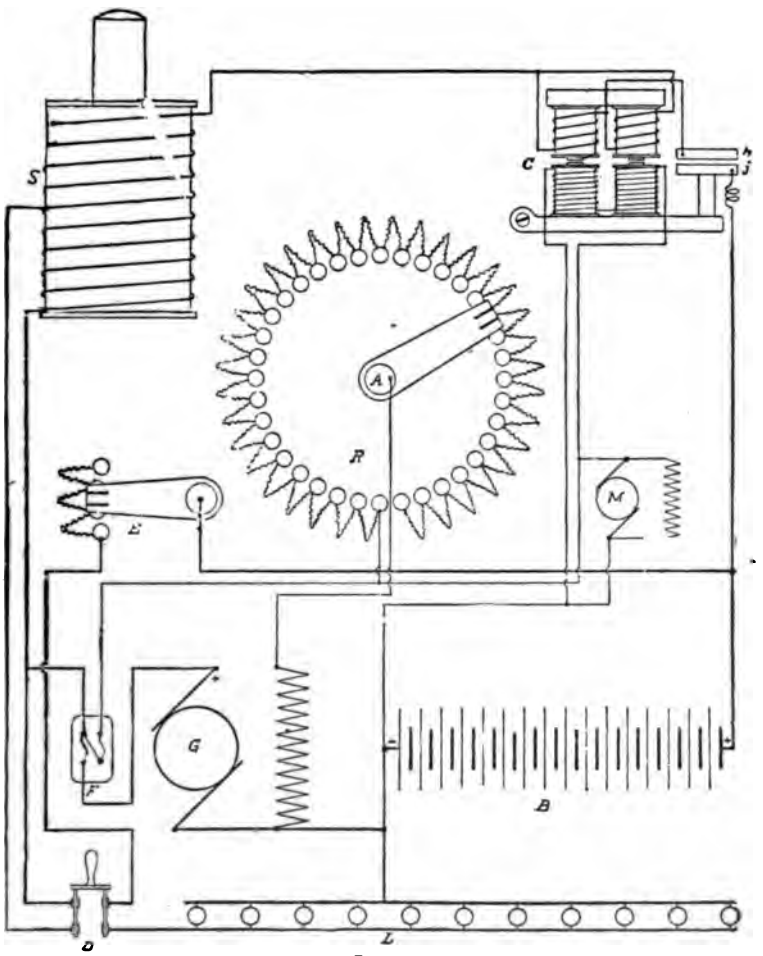
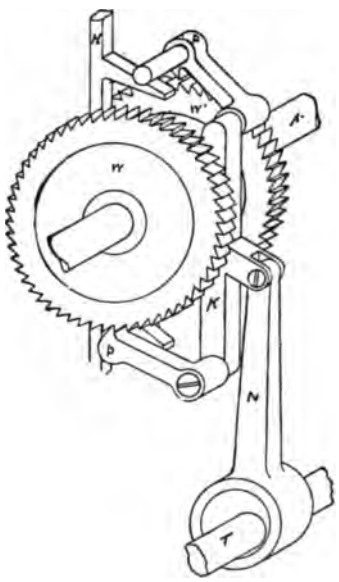


FIG. 4.

Details of the ratchet mechanism are shown in Fig. 5, where A is the generator field rheostat shaft, upon which are secured the ratchet wheels w and w′. The vertical link H, a portion of which is shown, is worked directly by the main solenoid plunger (see Fig. 3). It is provided with two arms upon which slide

bosses cast upon the two pawls. When the dynamo is generating the proper current the position of H is such that neither pawl can engage its wheel. Any displacement of H up or down due to a variation of the dynamo current will throw into gear the upper or lower pawl, as the case may be. It is obviously impossible for both pawls to be thrown into gear at the same time.

The rocking piece K has a bearing upon the shaft A between the two ratchet wheels, and is moved by a rod and eccentric N driven by shaft T. The small motor shown in the lower right hand corner of Fig. 3, drives the shaft T through a worm gear. The motor is always connected to the generator terminals, as shown in Fig. 4, and therefore runs when the train is running.



At high train speeds, when the battery is being charged, the potential difference between its terminals necessarily increases; and to maintain the voltage at the lamps constant it is necessary to insert in series with the lamp circuits a resistance proportional to the increase in voltage of the battery above its normal discharge voltage. There is, therefore, provided a variable resistance shown in the lower left hand corner of Fig. 3. By means of a reach rod engaging through a roller, a circular cam upon the rheostat shaft A (not shown in the cuts) resistance begins to be thrown in the lamp circuits at the same time it is first thrown in the generator field.

The regulator is adjusted in each case for the average run of the car, so that it shall maintain the generator output sufficient to keep the battery charged without excessively overcharging it. As will be noticed on the wiring diagram, Fig. 4, the series solenoid may be partially short-circuited by means of the same switch that turns on the lamp circuits. In this manner, during the daylight run of the car the generator output is maintained at a small amount, but as soon as the lamps are lighted the output instantly increases, each value of the output being maintained constant.

To make the solenoid adjustment it is necessary to determine the average number of ampere-hours required per day for the lighting service, and to put into the system a certain percentage in excess of what is taken out, in order to take care of the various

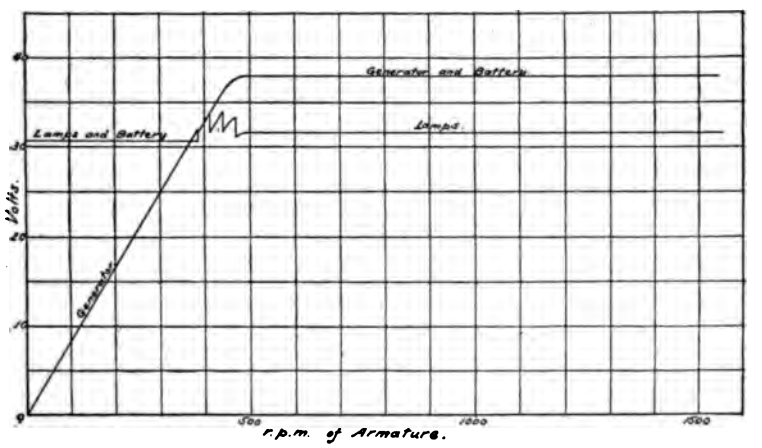


FIG. 6.

losses that occur. It is wise, too, to figure generously in this respect to take care of possible emergencies, and if this is done, there will be a certain time each day when the battery will be slightly overcharging. This does no harm, if not carried to excess, as the overcharging breaks up the sulphate that tends to form at times upon the plates. It is only continual overcharging or charging at a high rate that is injurious, and neither of these things can happen with the equipment under discussion, if the apparatus is properly adjusted in the first place and not changed thereafter, except to provide for new conditions in the run or service.

The curves shown in Fig. 6 represent a shop test of this apparatus. There was, however, no effort made to make the adjust-

ments with unusual care and the battery at the time was pretty well discharged. The jumps in the lamp curve just after the generator has "cut in," are due to the lamp resistance being inserted. This effect could, of course, be reduced by splitting up the resistance into a larger number of steps. The variation in the light, however, is very slight, and ordinarily is not complained of.

Except for those few moments when the lamp resistance is being inserted the voltage variation at the lamps can easily be kept within 4 or 5 per cent., which is very close for this class of service. The close regulation of voltage is also demonstrated by the fact that the lamps ordinarily furnished with these equipments are of very high efficiency, consuming only two and one-half watts per candle-power.

The power required to operate this system varies with the equipment of the car and the number of lamps it contains and varies from one to two h.p. per car. It is, therefore, insignificant compared with the power developed by a modern passenger locomotive. There is, moreover, no drag on the locomotive when starting, or until the critical speed has been reached, which on through trains is from twelve to fifteen miles per hour. Under this speed the armature is simply revolving with no other than frictional resistance.

The following table gives approximate data of the equipment:

EQUIPMENT.	CAPACITY.	SPACE OCCUPIED.	WEIGHT.
Generator	75 8 c.p. lamps.	33″ x 14″ x 13″	500 lbs
Regulator	75 8 c.p. lamps.	17″ x 19″ x 9½″	75 "
9 E Battery (Single) 24 lamps for 10 hours	160 amp. hours.	54″ x 20″ x 21″	865 "
13 E Battery (Single) 36 lamps for 10 hours	240 amp. hours.	72″ x 20″ x 22″	1280 "
9 E Battery (Double) 48 lamps for 10 hours	320 amp. hours.	85″ x 20″ x 27″	1730 "
13 E Battery (Double) 72 lamps for 10 hours	480 amp. hours.	91″ x 20″ x 36″	2560 "

A paper read at the 173d Meeting of the American Institute of Electrical Engineers, New York, February 27th, 1908.

SOME OF THE PROBLEMS OF ELECTRIC TRAIN LIGHTING.

BY GEO. D. SHEPARDSON.

The use of electric light in transportation is no new thing. The first commercial plant sold by the Edison Company to be operated by outside parties was installed on the steamship Columbia in 1879 at Chester, Pa., and began operation in May, 1880. Another of the very early isolated plants was used for lighting the shops of the Manhattan Railroad, beginning in the fall of 1881. At about the same time a plant was installed in the Baldwin Locomotive Works. The first Edison central station started at Appleton, Wisconsin, about August 20, 1882, and the larger Pearl Street station in New York City started on September 4, 1882, were antedated nearly a year by the application of electric lights to a Pullman sleeper running between London and Brighton, England, in October, 1881. The latter had 12 small lamps supplied from 32 Faure cells. This was so successful that by December of the same year the whole train of eight cars was equipped with 29 Edison lamps of 9 to 10 candle-power, supplied from 80 cells of storage battery. An electric headlight operated by steam engine and dynamo mounted on the locomotive was used on the Kronprinz-Rudolf-Bahn on the night of March 19-20, 1881, and was followed in December of the same year by others in France. As early as 1879, Hinkefus and Wesel took out a German patent on a train lighting system in which a dynamo driven from the car axle operated incandescent lamps. Even before the Pearl Street station was in operation, the Pennsylvania Railroad began experimenting with incandescent lamps operated by storage batteries under the cars, importing Faure cells from

France in the spring of 1882, and installing them on a car in August of the same year. Although this experiment was not a conspicuous success, the company renewed its experiments in 1884, and in the following year began the regular operation of electric lighted cars. From this beginning, the company has continually increased its electrical equipment, until recently it has adopted the electric light as standard for all passenger service.

From the standpoint of the railroad men, the requirements for a system for train lighting are reliability, safety, freedom from features objectionable to passengers, cheapness in first cost and low cost of maintenance. All of these requirements are matters of degree. For absolute safety from fire and explosion, nothing can equal the incandescent electric lamp when installed and maintained in accordance with established practice. The voltages used on trains are invariably low and well within the limits of danger or even discomfort to persons who might by some unusual way come into contact with the conductors. That the service may be made reliable is attested by the fact that many cars provided with no auxiliary light whatever are in use on such roads as the Chicago, Milwaukee and St. Paul, which has been using electric lights since 1890. The Pennsylvania road, which was the first in America to experiment with electric lights for car lighting, is now equipping all of its cars west of Pittsburg with electric lights, and is reported to be throwing out all auxiliary lights. The incandescent electric light is free from the smoke, smell, vitiation of atmosphere and the possibility of fire and explosion common to all competitors, and it yields such a moderate amount of heat that it may be said to be absolutely free from features objectionable to passengers, except those of occasional dimness or of infrequent unsteadiness. Furthermore, the advantage of adaptability to local and decorative lighting, such as dining table or berth lighting, and the possibility of advertising tail transparencies, the convenience of electric fan ventilation and of electric heaters, make the electrically equipped train the choice of fastidious travelers. In the matter of cost, electric lights compare favorably with others when quality and quantity are considered.

The application of electricity to train lighting is now over twenty-one years old, and may be said to have reached its maturity. It has not ceased to develop and improve but it has reached the age of responsibility and reliability. Like other adults, it still meets problems to be solved and looks forward to a bright future.

All of the various systems of car lighting which have been put into practical application have adopted constant potential direct current as the only satisfactory source of supply. The voltage varies from 30 to 110. The number and strength of lights varies through wide limits, some advocating 10 to 80 8-candle lamps per car, or 80 to 600 40-candle-power per car, some cars having as high as 26 50-candle lamps or 1300 candle-power per car. Tests made by the writer in 1900 showed an illumination in different cars varying from 0.008 to 7.5 candle feet. The stronger illumination is not only more pleasing to patrons and a conspicuous advertising agency, but further the flood of light effectually masks ordinary variations due to imperfect regulation.

The various plans for the supply of power for electric lights on cars may be classified as battery, dynamo and combination. The dynamo may be driven by an independent engine in the baggage car or on the locomotive, or it may be driven from the car axle. It may supply the lights directly, it may charge storage batteries or may combine the two. The battery may be large enough to supply all the lights through a single run or through a round trip, it may carry all the lights for only a few hours, or it may carry only part of the lights a short time for occasional use. Each of the various systems meets its own problems of mechanical, electrical and financial natures.

Battery Troubles.—When a battery is used without any dynamo on the train, it should have sufficient capacity to carry the load through the entire run without falling below normal voltage, a difficult task on long winter nights without excessive weight. Fortunately, the greatest amount of light is usually required when the car first leaves the charging station and when its voltage is highest; as the battery gives up its charge, the load generally lessens, and allows the voltage to remain fairly constant through the night. When properly proportioned to the load, the performance is excellent. For example, some of the Pennsylvania cars running between Chicago and Jersey City and charged only at Chicago, make the round trip with 32 to 24 volts at start and with 30 volts upon return. As the cells become old, however, their capacity decreases, and the battery lighted cars sometimes give unsatisfactory service toward the end of the run. For trans-continental service the unaided storage battery seems impracticable. The short time allowable for charging at terminal stations often involves excessively high rates of charging, and rapid lowering of the electrolyte. The difficulty of close and

thorough inspection of cells often results in no inspection until failure is reported. The difficulty of allowing good ventilation of the battery boxes while keeping out the dust and other dirt, involves difficulty from low insulation and from decay of the battery trays and boxes. Injury to car body and to battery boxes is minimized by liberal use of insulating paint, but seems difficult to avoid entirely. The shaking of the cells incident to railway usage causes somewhat more rapid deterioration than in corresponding stationary service. Slopping of the electrolyte is avoided by using deep jars with or without covers; the space is so fully occupied by the elements that there is comparatively little liability to slopping except in case of unusually violent handling of the cars. The weight of battery, including boxes, etc., on a car with "full battery" equipment is about 3,000 pounds, which is not a very large proportion of the total 91,000 pounds weight of a coach or the 116,000 pounds weight of a sleeper. The first cost of about $600 per car for "full battery" equipment, in addition to $300 to $400 for wiring, is not great in comparison with $8,000 to $10,000, the cost of a coach, or in comparison with $16,000 to $20,000, expended for a sleeper.

When the battery is charged during the run, there is more or less loss and deterioration due to the overcharging necessary to reduce the liability to failure on account of incomplete charging. The excessive charging and occasional over-discharging causes a more or less rapid deposition of mud at the bottom of the jars, which is liable to reach to the plates and so cause short-circuiting. The corrosion of connections due to the spray is frequently the cause of local action.

Engine Troubles.—On systems supplied from dynamos driven by steam engines, trouble is sometimes experienced from breaking of the flexible connection between the baggage car and the locomotive. It is common to use either the Moran ball-and-socket flexible joint or rubber hose strengthened by steel wire or expanded metal. The life of rubber hose varies from a few hours to several months. A blown-out hose can be renewed in a few minutes at the first stop of the train. There is sometimes trouble in disposing of the exhaust from the engine, which generally passes through the roof; when a good muffler is used, the grease is retained for the most part and is led through the bleeder through the car to the track, so that it is not carried back and deposited on windows and sides of cars. Sometimes in winter the condensed steam collects on the bellows of the car vestibules

to such an extent as actually to break the end of the car by the motion of the train. The reciprocating parts of the engines commonly used cause some vibration of the baggage car, which is transmitted through the couplings and may be felt to the extreme end of the train when in stations. The skill of the engineer in stopping the train is a large factor in the extent to which the vibration is felt through the train, it being least when there is a medium amount of slack. The adoption of the steam turbine may remove this difficulty. When the train is lighted from a dynamo and engine, some auxiliary source of light is necessary for the short intervals caused by changing locomotives, such relay being a storage battery or gas or oil lamps. The small engines use an excessive amount of steam per horse-power hour. The labor cost is not great; for example, on the Chicago, Milwaukee and St. Paul road each train on a run of 400 miles between Minneapolis and Chicago is allotted four baggage men who receive $10.00 per month additional wages on account of attending to the electrical equipment, making a cost of $1.33 for wages for 400 miles. On the Northern Pacific road, the baggage man has more than one man can handle, and an electrician goes with the train to attend to the engine and dynamo and to help the baggage man when necessary.

Axle System Troubles.—One of the greatest difficulties has been to secure satisfactory mechanical connection between the car axle and the dynamo. Gearing, belting and friction drives have been attempted with some degree of success. The latitude of motion of the car axle in three dimensions imposes upon the dynamo drive very difficult conditions. This with the difficulty encountered from the dirt and stones thrown up by the motion of the train and from the steam and snow or rain which may freeze upon the belt, imposes a problem whose satisfactory solution has required great ingenuity and expensive experimenting. That the axle systems are being adopted extensively is a triumph indeed. Direct gearing similar to that used in electric railway practice has attracted many minds, the danger from a hot box or defective gear on a railway train drawn by a locomotive of several hundred horse-power is a very different thing from a similar defect on a car moved by the geared motor itself, which is protected by fuses and circuit breakers. The next great trouble is the wide range of speeds met in train operation and the necessity for maintaining constant voltage from the time when the train is standing, through the point where the dynamo cuts in and

takes the load, to the highest speed attainable. The problem of regulation under such circumstances is one of no mean magnitude, and many are the ingenious plans proposed for its solution. Not only must the regulation take care of the varying speed of the train, but the battery voltage changes according to the state of charge, so that resistance or its equivalent must be inserted between the lamps and the dynamo or battery according to circumstances in order to keep the lamps at normal voltage. When one watches the operation of an axle lighting system which is so carefully designed and adjusted that no perceptible change occurs in the brightness of the lights between standstill and full speed, between the time when the battery is discharging and when it is charging, one can not but admire the success of the engineers in charge.

Financial Considerations.—All sorts of figures are given in connection with the cost of electric train lighting systems, some showing that each electric system is more expensive than any other, others showing that some particular electric system is the cheapest. The real cost varies greatly, according to the intelligence with which the whole plant is operated, this intelligence including both that of the engineer in immediate charge and that of officers of the road, who limit his facilities for proper handling of the equipment. In any case, the entire cost of maintaining the electric lighting system is a very small proportion of the entire cost of running the train, including not only the " operating expenses " but also that part of the general expenses chargeable to the particular train. The latter part of the cost, which is no inconsiderable part, is not usually obtainable. From the cost of operating the electric lights should be deducted the net profit from the added traffic which is attracted from other roads or which is created by the improved luxury of travel on electric lighted cars. These data are difficult, if not impossible to obtain with accuracy. If the added revenue created by the electric features of a train bears to the entire revenue from the train as great as or greater proportion than added cost of electric light, above other forms of light bears to the *entire* cost of running the train, then the electric light pays for itself.

Discussion.

PRESIDENT SCOTT:—The subject is now open for general discussion.

PROF. CARHART:—If I am allowed to speak at all, I shall have to speak as a free lance, especially as I know nothing about the subject in hand this evening. I have been a little impressed in listening to the papers read here with the fact that I have been uncertain part of the time whether the expert was giving the prior art or whether he was telling us about present practice. I think there was rather too much of the prior art in some of the papers, if you will allow the criticism. I was also interested in Prof. Shepardson's paper in speaking of the low voltage used in train lighting, which feature is very desirable because it avoids any accident in case a passenger comes in contact with the conductor. I have known cases on the Pullman cars where the passengers came in contact with two conductors at once; and my friend, Mr. Smith, says they may come in contact with three, the other two and the electrical conductor, and so I suppose that would be a three-wire system.

The thought occurred to me while we were hearing about these elaborate systems to secure constant voltage, and certainly they are ingenious—I admire greatly the ingenuity displayed in these two systems for securing constant potential—the thought came to me, why is it not possible to use the mercury vapor lamp which does not require a constant potential. Mr. Steinmetz tells us in a recent paper that the mercury vapor lamps will work between a very wide range of potential without any particular difference in the light given out. If that is so, we do not need these elaborate devices for maintaining constant potential. Mr. President, I am not able to contribute anything else to this subject, because I have not studied it.

PRESIDENT SCOTT:—The subject is open for general discussion.

MR. LAMAR LYNDON:—Some of the papers read this evening have seemed to assume that speeds of sixty miles an hour are sufficient. We have been informed by certain railway men that there are times when speeds of eighty-five miles an hour are attained for short stretches. No matter how short these stretches may be, the car lighters must be designed to take care of such excessive speed. Then, in regard to the battery end, there seems to be a disposition on the part of designers to take it for granted that a battery will maintain about two volts. It will not. A battery will require, in order that it shall be properly taken care of, a charging current that will run as high as 2½ volts. It must be discharged down to 1.8 volts. That is a variation of .7 volts, or about 30.5 per cent., taking 2 volts as the normal. These systems mostly assume that a constant current will flow into the battery, and that with variations of current we have variations of electromotive force, at the terminals, which is true; but we have further variations of electromotive force at the terminal due to the changing condition of the battery, and any system based on

charging with a constant current or maintaining a constant current through the battery cannot maintain the batteries in good condition. The proper way to charge the battery is that the current shall go in rapidly, when the battery is fully discharged, and that the current shall gradually be reduced until the battery rises to its maximum voltage, and in order to do that the generator must raise its voltage continuously with that of the battery, but not in such manner as to cause a constant current to flow through. A proper system must contemplate such a continuous rise in the voltage, that when the battery is fully charged, practically no current will flow through it; and those constant current systems, or systems which assume a constant current, will not maintain the battery in good condition. It must be what is technically known as "boiled" at times, or overcharged.

Mr. Farnsworth has stated that about 90 per cent. of the systems throughout the world use a belt drive. That is true, because they were originally developed abroad where the systems are very small and the lighting of a small English or German passenger carriage, and the equipment required, are by no means comparable to the lighting of a Pullman car in this country; and it is a difficult matter to drive such a generator with a belt, or take care of the generator or regulate it by belt slippage. I know of one system which was originally used in England and the patent rights for its use in this country were purchased here; and after the system was brought here it had to be totally re-designed for American service, and it took three years to get it in proper shape.

I would like to ask Mr. Bliss if he will please explain more fully the triple-contact employed in his system.

MR. BLISS:—I do not think I can explain it in any more concise form than to read the description of it in the text.

PRESIDENT SCOTT:—If the matter is fully described in the text of your paper it is hardly worth while to take time to read it.

MR. BLISS:—I will make this explanation, however. The triple contact shown in the diagram, Fig. 7, is drawn in duplicate which makes it appear as if there were two such contacts. As a matter of fact there is only one. It has been transferred from its true position as a part of the generator switch, to a position near the bucker simply to show more clearly what the contact is for, and how it is connected. If the wires leading to it were carried across the diagram there would be some confusion with a number of crossings, and it would be more difficult to understand. We call it a triple contact, because there are three things connected together by the plug. The three segments shown are connected respectively to the negative lamp main, the negative of the generator and the negative of the storage battery. You can see that when the batteries discharge, current will flow from the positive pole through the lamps, lamp bucker and backward through the series field to the negative pole of the batteries. There is a little drop through the lamp

bucker and series field, and it is desirable to short circuit these parts by connecting the negative lamp main directly to the negative of the battery. Such a short circuit would, however, convert the lamp bucker and series field into a local short circuited series dynamo, in which a heavy local current would circulate. To prevent this the negative of the generator is connected to the third segment of the triple contact, which short circuits both series field and lamp bucker, thus rendering same absolutely inoperative. The plug connects the three segments together just before the generator switch opens. Thus, at speeds below 20 miles per hour, during which the generator is disconnected from the system and the services of the bucker are not required, the latter is completely cut out or short circuited.

When the generator has attained a speed corresponding to 20 miles per hour, the generator switch closes, and at the same time breaks the triple contact. The parts of the bucker are now free to act as soon as current flows through the series field in the charging direction. As explained in the text the bucker is prevented from becoming a booster when current flows in the wrong direction through the series field by causing the motor armature current to return to the generator through the series field, but in a direction opposite to such improper discharge current. The simplest way to connect the motor would be directly across the generator mains, but as pointed out it is more advantageous to connect it as shown. The triple contact also serves to cut resistance in and out of the circuit of the lifting coil of the generator switch as described in the text. This arrangement also makes it possible to reduce the size of the switch and its cost of manufacture.

PRESIDENT SCOTT:—The Secretary has received a telegram reading as follows: " Please invite in the local Philadelphia Committee's name, Messrs. Bliss, Farnsworth and Sperry, to present abstract of their papers at local meeting, March 9th. W. C. L. Eglin."

The Philadelphia Local Branch is to inaugurate its work on March 9th, at the rooms of the Engineers' Club at Philadelphia. I extend an invitation to the gentlemen named to be present at that time and ask them kindly to communicate with the Secretary whether they can be there or not. I would say to the other members of the INSTITUTE who can conveniently be in Philadelphia at that time, that I am sure the Philadelphia members will appreciate very much your attendance at their meeting.

Mention has been made of the mercury vapor lamp. At the meeting of the Pittsburg Branch recently, at which the subject of illumination was discussed, a short paper was presented upon the Hewitt lamp by Dr. von Recklinghausen. He is with us this evening, and will, I think, give us a few remarks upon that lamp.

DR. MAX VON RECKLINGHAUSEN:—A few of the gentlemen have mentioned the mercury vapor lamp to-night in connection with

its possible use for train lighting. I am afraid they will be up against the same problem that we of the Cooper-Hewitt Company are up against in trying to persuade the public, especially the ladies, to consider the mercury vapor lamp a nice light. As to the lamp being put to such use under the varying voltages which are met with in train lighting, that is a thing I cannot say very much about, practically nothing, except that it is a very ticklish question and not at all as simple as it may seem to be from a recent publication. I do not think we are in a position to say anything about the vapor converter just now.

PRESIDENT SCOTT:—A gentleman who can talk on this subject, not from a theoretical standpoint, but as the result of large practical experience, is Mr. George W. Blodgett, of Boston. I believe he is present and we should like to hear from him.

MR. BLODGETT:—I had some experience quite a number of years ago in lighting cars electrically by the use of storage batteries. The Boston & Albany Railroad fitted up two trains running between Boston and New York, and for two years lighted them entirely by the Julien storage battery system, a battery being placed in each car. At first the batteries were charged only at one end of the line; but when it was found unsatisfactory to attempt to make a round trip with only one charging, arrangements were made to charge the battery at each end of the line. A switch was placed in each car which, thrown in one position, put all the cells in series. There were two batteries, one on each side of the car, which were put in series for charging, and also connected to a pair of dynamo terminals under the car on each side, and it was then only necessary to insert a pair of plugs in these terminals, which were of different size, so the poles from the generator could never be misplaced and the battery be discharged instead of charged. This was connected to an arc light direct-current circuit, which was the only means available for charging the batteries. Throwing the main switch in the car into the opposite position, put the two batteries in multiple and connected them to the lighting circuits, the lamps being turned on by a snap switch such as are employed in other lighting circuits. Had the storage batteries then used been of as durable quality as are now manufactured, I am not sure but the trains would be running to-day; but the deterioration of the batteries was a source of very great expense, renewals requiring to be made constantly so that the battery gave rather unsatisfactory service. The reason for discontinuing the lighting of these trains by electricity at the moment when it was done, was the shutting down of the electric lighting plants in New York City for a time, which prevented the batteries being charged at that end of the line; and it was necessary, therefore, to stop the electric lighting.

Some interesting things were found out about the lighting of cars with storage batteries, and it was a very instructive experiment I think I am correct in saying that these were the

first trains ever equipped for being lighted entirely by electricity. I am open to correction if I am wrong, but I believe that is the case. I hardly think there are any more facts of importance to communicate, unless some one has a question to ask.

A MEMBER:—In what year did this experiment take place?

MR. BLODGETT:—The experiment began in 1887 and ended in 1889.

PRESIDENT SCOTT:—The subject is now open for further discussion.

MR. C. W. HOGAN, Harrison, N. J.—Mr. Farnsworth stated in his paper that the voltage variation can be kept within 4 or 5 per cent. I think in central station arrangements the variation is 2 per cent., or thereabouts, that is, with lamps requiring from 3.1 to 3.5 watts per candle. In train lighting, where they use such an efficiency as Mr. Farnsworth states, 2.5 watts per candle such a variation would bring the lamps to 2 watts per candle, and would have an appreciable effect on the life of a lamp, on its maintenance of candle power, and its general appearance in the car. I think if this system of train lighting is to become a success, that this variation of 4 or 5 per cent. will have to be materially improved, from the standpoint of the life and maintenance of the candle power of the lamps.

MR. FARNSWORTH:—In regard to the point just brought up, the voltage of the lamp plays a very important part. For instance, a low voltage lamp, 30 volt lamp, has a stronger filament and is not so delicate as a higher voltage lamp, of the same candle power and efficiency; and although the life of the lamp is not particularly long, it is sufficiently long.

MR. LOCKWOOD, Detroit.—Is the discussion open to others than members of the INSTITUTE?

PRESIDENT SCOTT:—We would be pleased to hear from you.

MR. LOCKWOOD:—I have listened with a good deal of interest to the papers read to-night, and noted in Mr. Sperry's paper the statement that "A perfect system rquires that every car shall be entirely independent of every other, and shall maintain its lights perfectly after the train is broken up." It seems to me there should be added to that—and should be as simple and with as few moving parts as possible. On that point I would mention it is but a week since that one of the manufacturers of steam turbines informed me that his company had orders for a number of steam turbines to drive generators for use in train lighting. I note the title of the subject under discussion is "Railway Train Lighting," but the three different papers have simply described systems pertaining only to axle-driven machinery. If something could be heard about what has been accomplished with steam-driven machines, and also from the railway standpoint how the two systems are viewed comparatively, it would be interesting; because with the axle-driven machines, on the average train of from six to twelve cars, it means six to twelve equipments, with the necessary multiplica-

tion of parts, while with the steam-driven equipment but one would be needed for each train. It seems to me that simplicity is the most important point unless experience has proved it to be a failure.

MR. BLISS:—We have with us to-night a gentleman who, I think you will agree with me, has probably had more experience on this subject than any of the rest of us here present, and that is the electrical engineer of the Pullman Palace Car Company, Mr. J. R Sloan.

MR. SLOAN:—Mr. President and Gentlemen:—I regret exceedingly that my position and the Company's are such that it is not considered desirable I should take part in this discussion. I thank you very much for the invitation.

PRESIDENT SCOTT:—There is another system of train lighting which has barely been mentioned, but not commented on to-night A brief reference was made at one time to the stage coach, with horses furnishing the motive power, and nothing but a candle light to supply a little illumination. Later we come to the railway trains, driven by steam engines and lighted by oil lamps. When we try to transform part of this latter equipment and furnish electric current for illumination, various difficulties appear. Instead of doing part of the work with electricity, why not do it all? Let electricity take the place of the horse and the candle and also of the steam engine and the dynamo and the battery, and let us run the car and do the lighting by the same agent, and see how simple it will be. Mr. Henry G. Stott, electrical engineer of the Manhattan Railway Company, is running a system of that kind, and we would be pleased to hear from him.

MR. STOTT:—I was thinking how easily we could solve the problem in the way you indicated just now, Mr. President, taking the whole car and applying electricity to it in its entirety instead of to a part of it. I have been interested in the papers presented to-night. They have been as much a revelation to me as were the papers which we heard on the electric brake, two months ago. It is apparent that much work has been done in a quiet way in the most scientific manner, to solve the problem of train lighting difficulties. Those engaged in what might be called heavy electrical engineering perhaps neglect these points, and I think it is an extremely interesting development of the subject to find there are so many by-ways in electrical engineering of which the general profession hears nothing at all until the reading of a series of papers such as we have had to-night on this subject, and the papers on the subject of electric braking which were previously presented.

In Mr. Sperry's paper, reference is made to a new system. That is all we have heard in a definite way, and I would like to have a little further information on that point. The papers presented by Mr. Farnsworth and Mr. Bliss are so able in themselves as to be beyond criticism. Mr. Bliss' paper especially

shows us what can be done, not only in maintaining constant potential in lighting trains, but I think can be applied in many cases to obtain constant potential where we have variable sources of power, such as water power. I think in such cases the application would be a very similar one.

PRESIDENT SCOTT:—Is there any one present who is able to give Mr. Stott the information he asks for?

MR. SPERRY:—In reply to our President's remarks and those of Mr. Stott I find myself in the position of one having accepted an invitation to present a paper and at last moment finding that *Hamlet* had to be omitted, but the author not released. At no distant date will I be able to answer Mr. Stott fully, but the one who is responsible for a large part of the work that I have attempted to describe is here with us, and I should like to hear him say something with reference to the details asked for by Mr. Stott. I refer to Mr. Lyndon.

MR. LYNDON:—I should like very much to say all that I can about this system which has kept Mr. Sperry and myself very much engaged for the past eighteen months, but we were told to-day by our attorneys that we could not do it; and, therefore, I think that Mr. Sperry's suggestion that I should speak to you on this matter is getting even with me for something I never did.

PRESIDENT SCOTT:—The attorneys must be respected, but we are glad to know, in a general way, the information which you have given about the system.

MR. LYNDON:—I think in explanation, Mr. President, that I should say that when we agreed to present this paper it was supposed our arrangements would be completed before the paper would be presented. We did not intend simply to give a general paper to the INSTITUTE, but to go into more specific details. We have, however, lately been informed that the arrangements were such we could not give any more than we have.

PRESIDENT SCOTT:—Is there any further contribution to the discussion?

MR. W. N. SMITH:—As one of the recent speakers remarked, nearly all of the subject matter of the discussion to-night has been on axle-driven systems. The ingenuity the members have displayed is truly remarkable. At the same time, quite a little car-lighting is done by the old-fashioned steam engine driving a direct coupled generator in the baggage car. None of the gentlemen have stated how long or on how many trains their respective systems have been in successful operation, and it seems to me that a little information as to what the commercial results have been, would be fitting in this discussion. I believe the system that I have in mind with a high speed engine and generator in the baggage car, receiving steam from the locomotive, is applied to most of the finest and fastest electrically lighted express trains on quite a number of the principal railroads of this country, like the New York Central; Lake Shore; Chicago and Northwestern; Chicago, Milwaukee and St. Paul; Northern Pacific, and several

others. It would be very interesting, indeed, if we could hear upon what railroads these axle-driven systems have been applied, and how many of them have been accepted and are in daily use on the prominent railroads of the country.

MR. BLISS:—I regret that Mr. Sloan cannot tell us something about the lighting on the Pennsylvania Limited, of which he has immediate and direct charge, but as he seems to be reluctant about doing so, I will venture a few remarks on that subject myself, and stand correction from him or anyone else if I am in error.

The system of lighting on the Pennsylvania Limited which is probably the most celebrated train in the country, consists simply of an engine and generator in the baggage car, train lines through the train and storage batteries on the cars. For many years they have employed a Brotherhood three-cylinder engine, directly connected to an Eickmeyer generator, running at 800 r.p.m. The system is not complete. At best, these generators could furnish just about enough current to charge the storage batteries alone or else light the lamps alone. When charging the batteries, it was not safe to use the lamps on account of the high voltage, but as a matter of fact there was not sufficient power in the engines to perform both operations at once. When the Brotherhood engine was in good condition, it developed a horse-power-hour with something like 80 lbs. of steam, but I have heard that nearly 500 lbs. of steam have been consumed per horse-power-hour in actual test. Within the last few months, there has been installed a De Laval steam turbine driving a generator at 2,000 r.p.m. The apparatus runs very satisfactorily and shows a good steam economy, about 25 lbs. of steam per horse-power-hour. This new equipment takes up more room than the original plant, and requires the constant care of an engineer. It occupies practically one-quarter of the space devoted to baggage, the car being a combined parlor smoker and baggage car. There is ample power in this plant to charge the batteries and light the lamps. The machines run smoothly and without vibration, but make a great deal of noise by reason of the gears, which operate at such high speed. The noise cannot be heard outside of the baggage compartment and no vibration is communicated to the train, as was observable, for instance, on the Lake Shore Limited, where the knuckle in the coupler in the rear car could be seen shaking when the train was standing at a station with the engine and generator in operation. As a system, the turbine set is no better, except in economy, and greater capacity than the original plant, which it has replaced. The difficulty still to be overcome is that the storage batteries cannot be charged and the lamps lighted at the same time and the batteries on this train, with its turbine generator and up to date equipment, still have to be charged at Jersey City and Chicago as of old. A number of devices have been suggested whereby resistance or something equivalent could be thrown into the lamp circuit to maintain

proper voltage on same, while the batteries are being charged; but these devices, if automatic, are difficult to make, and if the porters are to be depended upon to operate them, they will be unreliable. It seems to me that a system is necessary whereby the lighting of the lamps and the charging of the storage batteries can be carried on simultaneously without any rise in voltage on the lamp circuits. Thus we see to-day, on the best-lighted train in America, the Pennsylvania Limited, the system of lighting is very far from being perfect and in fact as a system it is not much better than it was fifteen years ago.

MR. SPERRY:—I would correct a statement of the next to the last speaker, that the fast trains are all fitted with dynamo sets. As I understand, that is not true. The Twentieth Century Limited, and all that series of trains, have axle-driven equipments, and there are some other fast trains with axle-driven equipments as against the system of employing a single generator for the entire train. The want of discussion on this type is, I think, owing to the fact that in this case, employing the single generator in the train, we have conditions similar to those of a central station with its coupled lamps. It entails no special problem, and the discussion to-night has been on the special problems which are presented in axle power, and which have been overcome in such meritorious ways as we have heard described.

With reference to the detail of the system, which I was invited to describe and which at one time was described in my paper and afterwards expunged, I would say that the generator is simply a constant speed machine. The item of regulation is reduced to a very simple and straightforward mechanism, which is introduced between the driving axle and the dynamo, in which it differs from the present types of car lighters, which are variable speed machines and which must have the variable voltage compensated for in the electrical system. The load comes on at 1,200 revolutions, which corresponds to 18 miles an hour train speed. When the car runs at 80 or 85 miles per hour, the 1200 revolutions are still maintained, thus eliminating the more complex problems involved in the electrical control and some of the complexities which exist in the other systems. One of the special points sought is the handling of the batteries in accordance with the best practice of charging storage batteries, not utilizing a small portion only of the range, but utilizing the battery throughout its whole range of possible operation, and maintaining the voltage of lamps within one half of one per cent., instead of the large percentage of variation that we have heard discussed to-night. This permits of the use of more delicate lamps—higher efficiency lamps, I might say. These features are among the essential points of difference between this and the other axle systems about which we have had the pleasure of hearing to-night. Another essential is the automatic charging with lowering current when battery is nearly charged, and still another is the utilizing

of measurably 100 per cent. of the normal capacity of the cells, thus keeping them in a healthy state, and requiring only a comparatively small weight of battery aboard.

I referred in the paper to a series of investigations that were conducted where I had an opportunity of observing the operation of the systems; a peculiar phenomenon in the case of one of Bliss' equipments came under my notice, which I think we would be interested in hearing Mr. Bliss explain; and that was the almost inexplicable fact that upon the accidental or other opening of the battery circuit, instead of putting the lights out, or cutting down the voltage at the lamps, all of the lamps in the car went *up and out;* and the voltage rising until the lamps and filaments were exploded. I have looked through the diagram and paper which Mr. Bliss presented to-night, but fail to see any reason given why this should have occurred, possibly he will explain it for us.

MR. BLISS:—In answer to some of Mr. Sperry's remarks, I would say, in regard to the transmission of power from the axle to the generator, it seems to me that the problem is much like that in a street railway motor, and we can be guided in dealing with it by the experience of those who have worked that system out to perfection. When Mr. Sperry speaks of a constant speed generator, it pre-supposes that there must be something in the transmission that secures the constant speed. It seems to me simpler to allow the speed of the generator to run wherever it will and take care of it electrically which can be done more easily than it can be mechanically.

In regard to the other point which Mr. Sperry brings up. If the storage battery circuit is broken, what will happen? If the battery circuit opens, the regulating current through the series field is interrupted and the voltage of the generator will rise abnormally and may result in great damage. We do not furnish the storage batteries and are not responsible for them. Is it, however, incumbent upon the storage battery people and the railroad companies to see that the lugs and connections of the storage battery are properly made and installed. We have introduced a device which I have not touched upon to-night, not because my attorneys have advised me not to, but simply because I have not so chosen. I am free to speak to you of this device, whereby the destructive effects of excessive voltage are avoided. This device was made necessary principally through the repeated breaking of the storage battery lugs, for which we are not responsible, but which, nevertheless, reflects upon us. This device is simple in its construction and will act in two ways. It will prevent an abnormal rise in voltage in case the storage battery circuit opens and it will also operate to discontinue the charging of the batteries, when the latter have become fully charged.

One other point Mr. Sperry brought up. He said that a train equipped with an engine, generator train lines and storage bat-

teries was simply a small central station and introduced no new problems to solve. But the problem has not been solved at all. As a system it is incomplete and it is not even a self-supporting central station in the sense that it is independent of outside power. Terminal charging still has to be depended upon. The engine and generator in the baggage car will not maintain light in the passenger cars in the present state of development of this system.

MR. JAMES F. MCELROY:—I did not intend to take part in the discussion on this subject, but since entering the room the Secretary has requested me to say something about the system of axle lighting with which I have been experimenting for several years, and I may wish the privilege of publishing, in the report of this meeting, a short article descriptive of that system, if it is in conformity with the rules of the INSTITUTE.

PRESIDENT SCOTT:—That will be satisfactory.

MR. MCELROY:—I will say that in my experiments, I have tested almost every conceivable apparatus for driving from the axle. My first experiments included the use of belts made of leather of single and double thickness; part of these were wide belts and part narrow. I have also used rawhide belts, the so-called camels' hair belt, rubber belts, link belts, and I have lost so many belts that I have called the line between Albany and Montreal, where my apparatus was in use, " the belt line." I employed a tension device to maintain the proper tension upon the belt. In one set of experiments I attached the generator to the bottom of the car and undertook to drive direct from the pulley on the axle. I also made another device in which the dynamo was capable of a side motion so as to maintain a parallel position between the dynamo shaft and the car axle. I found that whilst certain difficulties could be removed, other difficulties persisted throughout my experiments and caused me to abandon the use of belts. For example, I found that a belt which would run all right when dry would not run satisfactorily in wet weather; or belts that operated when the thermometer stood at 40 or 50 degrees above zero would not act properly when the thermometer fell to 20 degrees below zero. The heating apparatus on the car, discharging the water of condensation, may have been in a measure responsible for the formation of ice over the pulleys and for the consequent lack of adhesion between the pulley and belt.

I remember leaving Albany on the sleeper one night at 11 o'clock, bound for Montreal. The next morning, as we approached Montreal, I stepped into the car just ahead, which was equipped with my lighting apparatus. The lights were running all right, but when the train stopped I noticed that the pulley on the axle had a half inch thickness of ice upon its surface between the belt and the pulley. You must admit that such conditions are not favorable to the use of belts.

Now, there are some peculiar difficulties in the use of belts for

this apparatus. The question of adhesion between the driving pulley and belt is by no means the only one. I believe that the question of alignment introduces some very serious complications. I have found that an axle on a straight track does not maintain a position perpendicular to the line of the rails or to the line of the car. It is well known that the tread on a car wheel has a larger diameter near the flange of the wheel than it has at the outer edge. There is a play of fully half an inch between the flanges of the wheels and the rail. The result is that when one flange crowds up against the rail, that wheel runs on a larger diameter than the opposite wheel on the same axle. The first wheel, therefore, moves forward more rapidly than the opposite wheel, and this motion then crowds the flange of the opposite wheel against the rail, when it in turn drives forward more rapidly. The result of this peculiar action is a see-sawing of the car axle, in which it moves so as to bring alternate flanges in contact with the rail and at the same time the axle is given a to and fro motion, lengthwise of the axle. This complicated motion introduces difficulties when you attempt to drive a dynamo with a belt on a pulley on the axle, as it causes the belt to see-saw across the face of the pulley, striking the flanges on both sides and causing the tension to be thrown first upon one edge of the belt and then upon the other. This action results in stretching the belt along its edges.

The axle also has another motion which is especially noticed when the air brake is applied, which pushes the axle towards the king-bolt and thus increases or decreases tension upon the belt, depending upon which side of the axle the dynamo is supported.

Another difficulty in the use of belts is caused by the spring used to maintain tension upon the belts. When an engine backs on to a train so that a shock is given to the car, a severe blow is given, which causes a sudden increase of tension upon the belt; or if the blow is in the opposite direction, causes the tension suddenly to release, when the spring device will then pull the dynamo back quickly, when it strikes with heavy force within the belt. As a result, belts are often broken in the making up of trains at the station

I feel quite at liberty, Mr. President, to speak of my experience with belts, since my experiments in car lighting have carried me to a point where belts are entirely discarded. I have no reason to believe that my experiments with belts in lighting apparatus were any more unsatisfactory than the experience of other companies in the use of belts. I believe that the experience of all companies attempting to operate lights from the axle by means of belts, is that the belts have been short-lived, unreliable and unsatisfactory.

In my own apparatus I now use a gear and pinion somewhat resembling the arrangement as used on the electric cars. The gears are noiseless, giving a positive drive, and the wear for the last year indicates that the gears and pinions can be furnished at a cost not exceeding $5 per year.

Reference has been made by two of the members in the discussion of the storage battery and the fact that the storage battery when nearly depleted should receive current at the maximum charging rate, and that as the charging operation proceeds, the rate should be gradually reduced so that by the time the battery begins to gas at the completion of the charge, the flow of current through the battery should be reduced to a minimum. I fully agree with that statement as to the proper method of charging a storage battery, and I desire to say that I invented and have had in use for a number of years a method of control which enables me to charge a storage battery precisely in accordance with the formula as laid down by storage battery makers. In other words, when the battery is depleted, the charging rate is at its maximum, but still within bounds The charging rate gradually tapers as it approaches complete charge, when the sudden rise of voltage, due to gasing of the battery, after the completion of the charge reduces the current to zero. This result is accomplished in the regulator by the use of a peculiarly constructed suction coil. The plunger of the suction coil is drawn out by a spring under constant tension. The pull of the suction coil then consists of two parts—the charging part, due to a shunt coil and the other, a minor part, due to a small series coil, which is placed preferably in the storage battery circuit. The total of the pull of the shunt and series coils is equal to the tension of the reacting spring. The result is that the voltage maintained in the charging of the storage battery is a modified constant potential, being lower when the battery is depleted than when the battery becomes fully charged. The greater flow of current to the battery, when depleted through the series coil, is accompanied by a smaller pull on the part of the shunt coil. As the counter electromotive force of the battery increases, the decreased flow to the battery through the series coil causes an increase in the pull of the shunt coil, due to the rise of voltage.

The result is that by adjusting the number of turns of the series coil, the rate of charging a storage battery may be brought absolutely under control, in accordance with any prescribed formula. I will say that whilst this method is patented, it may be of interest to you to know how this problem has been worked out.

PRESIDENT SCOTT:—A sentence in the paper submitted by Prof. Shepardson is well worthy of repetition, as we all agree that it is the sentiment of the whole trend of the evening. He says, "When one watches the operation of an axle lighting which is so carefully designed and adjusted that no perceptible change occurs in the brightness of the lights between standstill and full-speed, between the time when the battery is discharged and when it is charged, one cannot but admire the success of the engineers in charge." The whole discussion this evening has been a demonstration of the manner in which electrical engineers have attacked and solved some very difficult problems. I think the

great value of a meeting of this kind, with papers of the type which we have had, and with discussions and debates embracing experiences such as have been presented to us to-night, lies in this—that it presents the problem definitely to others and deters them from going over the same ground and making the same mistakes. Train lighting is a very attractive subject. As soon as one comes to understand a few of the difficulties which have confronted inventors in this and other lines of work, we begin to appreciate the effort which lies behind what are apparently simple inventions. A young man just beginning to try his intellect in an inventive way is apt to contrive some little device which will overcome some difficulty and then he thinks he has solved the whole problem; but this, as we know, is not often the case. If such a young man has been here this evening or will read the proceedings of this meeting, he will get a good deal of light on these lines. It will show him that many practical problems, simple as they may seem in themselves, really involve a great deal. Whole series of problems arise and if one attempts to investigate them and does so in ignorance of what others have done before him, he is apt to subject himself to an indefinite number of disappointments until he properly appreciates the fulness of the problem, in a manner such as we have appreciated the difficulties of train car lighting presented in the discussion this evening. If there is no further business, the meeting stands adjourned.

(Adjourned.)

[CONTRIBUTED AFTER ADJOURNMENT OF THE FEBRUARY 27TH MEETING, BY J. R. BIBBINS.]

Considering the subject of train lighting by electricity in its broadest aspect, it is necessary to reduce all methods to an unbiased competitive level, determined almost entirely by commercial considerations of: 1. First cost. 2. Cost of operation and maintenance. 3. Results to be obtained. There is no doubt but that the multiple-unit or axle-light system is the most attractive of the several methods advanced for train lighting, and the ingenuity displayed in some of the present apparatus worthy of highest commendation, by reason of the almost insuperable difficulties encountered; but the question of cost and results obtained are nevertheless paramount in the mind of the unbiased purchaser.

The following comparative table cites briefly the advantages and disadvantages of the two prevailing systems.

ELECTRIC TRAIN LIGHTING.

Multiple-Unit. *Axle-Lighting Outfit.*	Single-Unit. *Engine-Generator Unit.*
Advantages:	Advantages:
Independent car illumination.	Concentration of many small units under one control.
Power obtained from locomotive without intermediary connections.	Standard and efficient apparatus.
No attendance required en route.	Uniform rotation and voltage.
Disadvantages:	Adequate potential regulation.
Erratic current generation.	Absence of mechanical complexity.
Commutation difficulties.	Apparatus protected and in full view.
Small and inefficient units.	Higher gross efficiency.
Increased hysteresis loss at high speeds.	Small total weight.
Reversal in rotation.	Low initial investment.
Storage batteries essential.	Minimum depreciation and maintenance.
Inefficient power transformation.	Disadvantages:
Apparatus exposed and subject to jar.	Valuable space consumed.
High depreciation and maintenance.	Flexible conductor between cars necessary.
High initial investment.	Attendance required en route.
	Storage batteries required during disconnection of locomotives.

In directing attention to the single-unit system, it is not the intention to advocate any particular class of apparatus for ful-

filling the required conditions, but to emphasize the many important and vital features of the system in distinction to those of other systems so ably and exclusively championed at the last meeting of the INSTITUTE.

The single unit system is at the present time in successful operation upon a number of important roads running fast limited service of the highest character. The usual equipment consists of a 25 or 30 h.p. vertical two-cylinder engine, direct connected to a 17½ or 20 k.w., 125-volt D.C. multipolar generator, both mounted upon a common bed-plate, and installed in a small compartment in the forward part of the baggage car, directly over the forward truck. The engine receives steam at 100 lbs. pressure from the locomotive through a flexible hose connection. It exhausts through the roof, a suitable muffler being inserted for retaining oil and condensation and deadening the exhaust. The few meters, switches and simple wiring required are mounted upon the side of the car. The train-line between cars is established by means of a flexible cable with special lugs, which may be quickly connected during the make-up of the train. Storage batteries may or may not be employed, according to the nature of the train service, and are not essential to the operation of the entire electrical equipment. It is customary, however, to insert a small battery under the baggage car for furnishing current during change of locomotives. This procedure may extend to other parts of the train, such as dining cars and sleepers, which are to be disconnected from the train at stations en route.

The generating outfit weighs approximately 7,000 lbs., thus averaging but 1,000 lbs. per car in a seven-car train. This is but 30 to 60 per cent, of the weight of present multiple-unit systems per car. The unit stands 5 ft. high over all, and requires 25 sq. ft. of floor space. It may be conveniently installed crosswise of the car, in a compartment 6 ft. long, thus consuming from 9 to 10 per cent. of the baggage car room; or it may be left unhoused when this floor space may be somewhat encroached upon. The steam consumption of the engine averages 35 lbs. per i.h.p. hour by actual test and the efficiency of the generator is 90 per cent., at full load. Assuming the combined efficiency at 76 per cent., the net steam consumption at the locomotive approximates 45 8/10 lbs. per h.p., delivered at the generator terminals.

For purposes of incidental comparison with the multiple-unit or axle-lighting system, we may assume the steam consumption of an express locomotive to be 22 lbs. per i.h.p., its mechanical efficiency 85 per cent., and the corresponding figures of efficiency of car truck, mechanical drive, and small generator 90 per cent., 75 per cent. and 83 per cent. respectively. Upon this basis, the steam consumption of the multiple-unit system becomes 46.3 lbs. at the boiler. These latter figures are of course only tentative, but may serve partially to refute the popular argument that this system derives its power directly from the locomotive with no appreciable loss, by calling attention to the fact that

there are six distinct transformations of energy involved, as against two in the single-unit system. The figure 75 per cent. would probably be exceeded in properly designed gear transmission, but not in belt transmission, and especially not in apparatus involving slippage of friction discs, rollers or belts. According to present quotations, which may not be given here, the cost of a single-unit equipment ranges from 15 to 25 per cent. of that of a multiple-unit outfit, for a seven-coach train, together with the necessary batteries. The introduction of an auxiliary battery in the former system reduces this difference proportionately.

Maintenance and depreciation of the single-unit is evidently a much less important factor in cost of operation than that of the multiple-unit system. On one railroad, one of the single units has run successfully for 5½ years, averaging 12 hours per trip, while the particular type of engine used has to its credit a record run of 13 months, 8 days without stop, and a repair account during 12 years of operation amounting to 2 per cent. per annum of the first cost. The attendance required upon one of the roads above cited is furnished by the baggage-man, who receives $1.52 per day extra wages for the service, amounting to 22c. per car day or about $80 per car year. The cost of supplies and maintenance for the generating unit seldom exceeds $25 per year. The entire cost of operation, exclusive of the battery, thus totals considerably under $100 per car year. May it not be barely possible that the single-unit system, with all its faults, will successfully compete with its ingenious rivals on the score of reliability, durability and non-complexity, as well as that of low cost of investment and maintenance?

A paper read at the 2d Meeting of the Boston Branch of the American Institute of Electrical Engineers, March 26, 1903.

A SYSTEM OF ELECTRIC LIGHTING FOR CARS.

BY JAMES F. McELROY.

A modified constant-potential system of car lighting, employing an axle-driven dynamo which is capable of operation by motion in either direction.

There is a wide variation in load which axle-driven apparatus is called upon to carry in actual service. If a car is operated wholly in day time, just sufficient current should be generated to maintain full charge in the battery or to supply battery losses; more than this amount is needless and wasteful and may be harmful to the battery-plates. On the other hand, if a car is operated only at night and must be lighted for some time before it begins its run, or has long and frequent stops, a very different problem presents itself. The battery should then receive its charge at a high rate and at the same time current must be generated for operating the lamps. In this case the current generated by the dynamo should be at a rate about twice that required for lamps alone. The actual demand upon lighting apparatus varies between the two extremes here referred to and consequently the lighting apparatus must provide automatically for correspondingly wide variations in load.

Incandescent lamps and storage batteries require constant voltage in the supply circuit. If a variable load is called for, it is evident that we cannot have a regulator controlled by the current in the mains as in that case there will be produced a constant current at a constant voltage, which will give a constant load. The variable load required must evidently be obtained by means of a constant voltage and variable current. These considerations should guide us as to the method of regulation to be selected.

The system of lighting cars which I will describe may be called a modified constant potential system. It employs an axle-driven dynamo which is capable of operation by motion in either

direction. Fig. 1 presents a view of the dynamo. It will be seen that the dynamo rests, at one end, upon bearings on the car-axle, while it is supported by easy-riding springs under the dynamo body. These springs rest upon curved supporting bars which are attached at one end over the car-axle bearings, and at the other end swing from pendulum supports to a cross-bar which rests upon the truck-frame. The dynamo is therefore free to move with the car-axle. The curved bar-supports facilitate the removal of the axle and wheels, when that is necessary, by dropping down out of the truck-frame in the usual manner. They also make it easy to open the dynamo as shown in Fig. 2 without

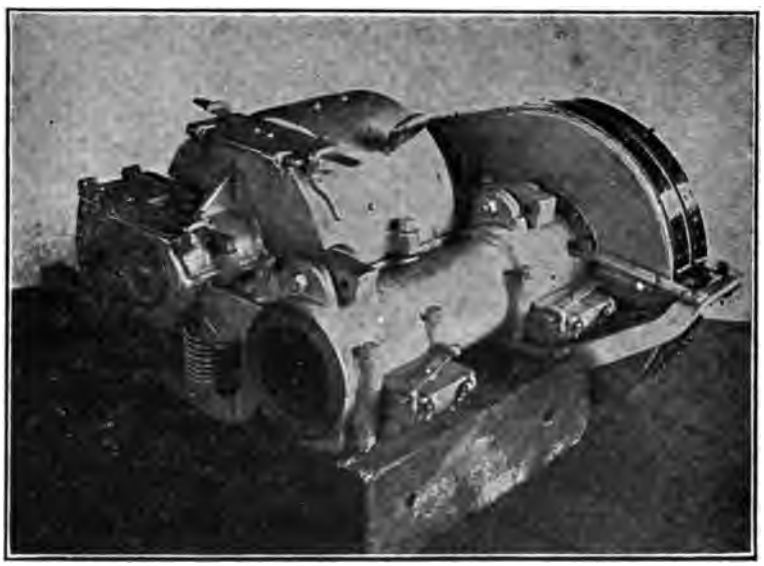


FIG. 1.

in any way releasing the dynamo from its supports. The dynamo is driven by means of gear and pinion in a manner somewhat similar to that employed on motors of trolley cars. A wrought-iron gear-case incloses the gear and pinion and is made dust-proof with leather packing.

All doors admitting to parts of the dynamo requiring inspection, as well as the doors for supplying oil and waste to the axle-bearings, close upon leather or felt packing and are held firmly in place by strong spring-latches of flat steel. All doors are in this way made dust-proof.

The compartment containing the reversing switch is shown at the left and in advance of the armature bearing. This switch is operated by the armature-shaft and reverses the connections of the armature to the mains. A door easily accessible admits to this chamber for purposes of inspection.

A storage battery is employed for supplying the lamps during stops. The battery receives its charge at all times when the dynamo is in operation, and the battery is below the point of full charge. The flow of current to the storage battery and the generation of current by the dynamo are regulated, through the

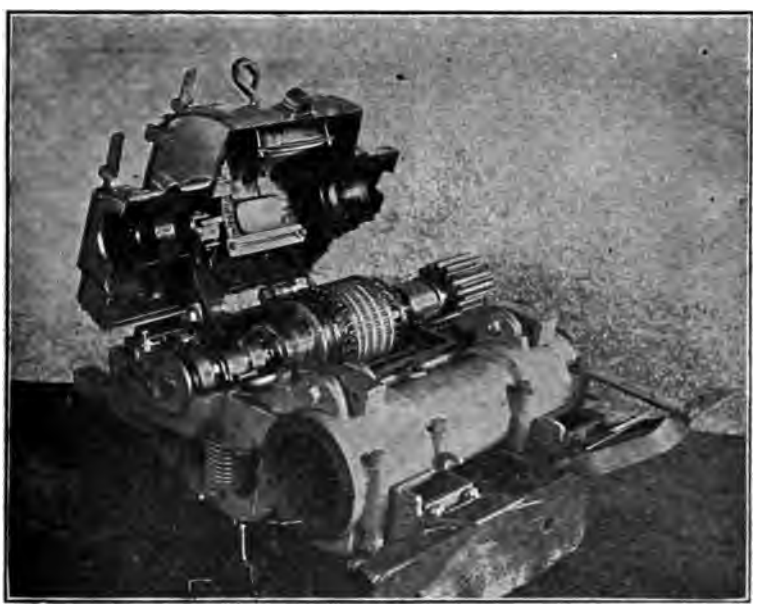


FIG. 2.

widest variations of speed, by means of the regulator shown in Fig. 3. In this regulator a motor, through worm and gear connections, operates a rheostat which is connected in series with the dynamo fields. The motor is controlled by a compound solenoid and plunger, the plunger being connected with an arm carrying carbon contacts by which the current is directed through the motor for changing its direction of motion. To insure the workings of the regulator under all conditions, it is necessary that the motor should be wound for large torque and low speed and be capable of operating at a voltage as low as the lowest voltage

ever carried upon a battery. It is also necessary that the changes in position of the rheostat should be made at a rate not greater than the rate at which the corresponding changes will take place in the field-magnets of the dynamo, otherwise the phenomenon of racing will cause a disturbance in the lights. To prevent racing, we use a centrifugal governor by means of which the circuit through the motor is completed between two stationary rings which surround the motor-shaft. Contact is made

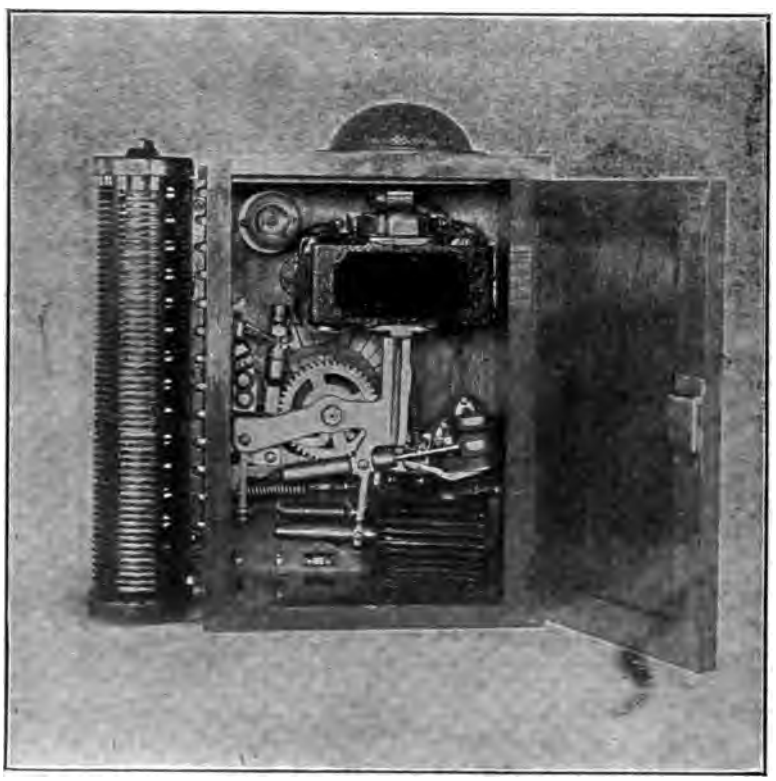


FIG. 3.

between these two rings by means of weighted arms which on the starting of the motor, immediately throw out and break the circuit. The result is that the governor gives to the motor a fixed rate of motion and this rate of motion is not increased or decreased within the limits of voltage at which the motor operates.

The centrifugal governor is mounted above the motor and within the perforated hood at the top of the regulator.

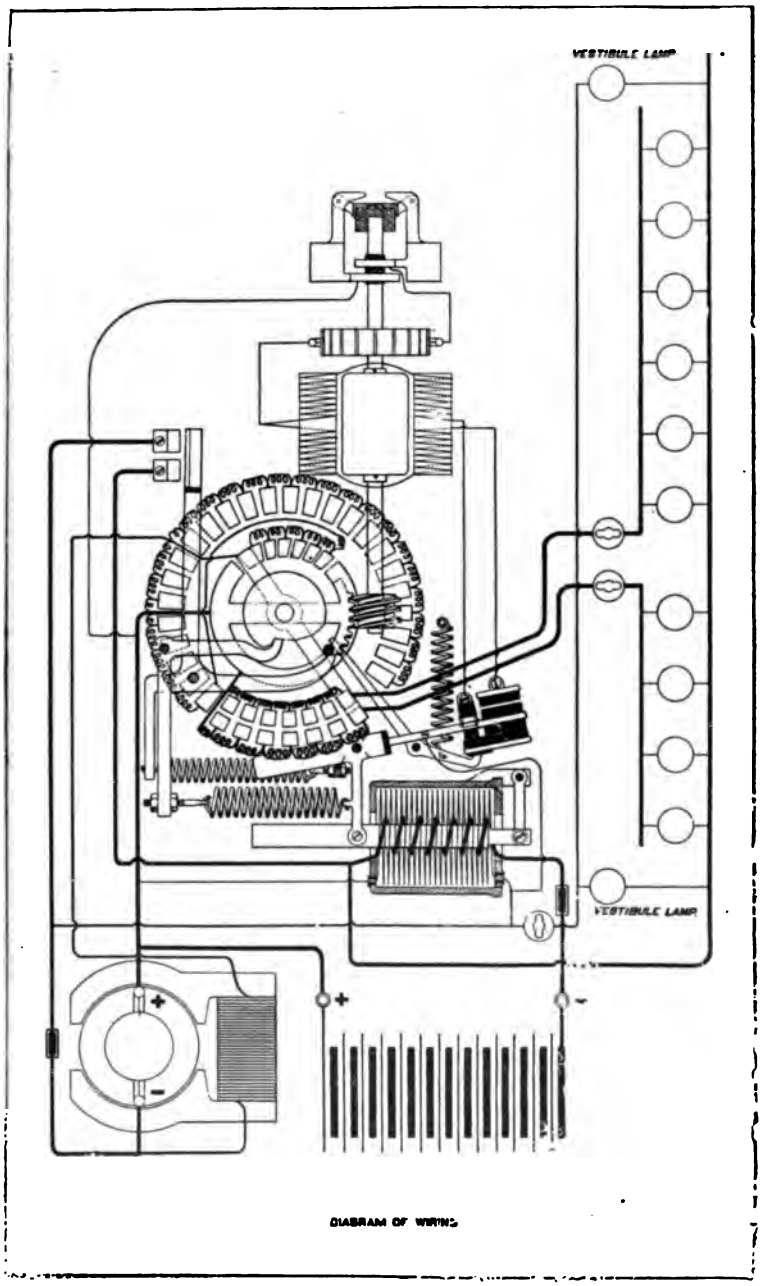


FIG. 4.

In the construction of this regulator the compound solenoid is placed inside an iron envelope which receives its support from the metal framework to which all of the working parts of the regulator are attached. The iron envelope increases the pull of the solenoid more than two times by furnishing a covering through which the magnetic flux is conducted back outside of the coil. At the ends the iron envelope is kept back from the plunger a distance of nearly three-eighths of an inch, to prevent the envelope from creating a side-pull upon the iron plunger.

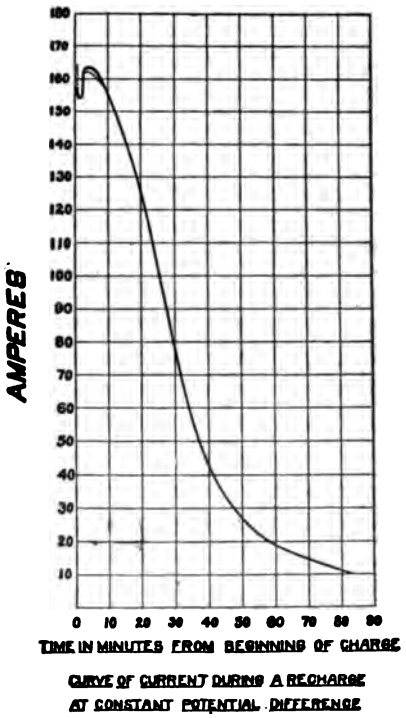


FIG. 5.

Longitudinal ribs are cast on the iron casing for the purpose of furnishing a path in the direction of the magnetic flux and at the same time for increasing the surface of the iron casing to permit of the ready escape of heat that may be generated in the solenoid.

The increased pull upon the plunger, due to the improved path for the magnetic flux, and the fact that the regulation is effected both by means of change of voltage and change of current to the battery, renders the apparatus very sensitive and positive in its action.

The switch for disconnecting the dynamo from the storage-battery is operated by the motor which drives the rheostat. The return of the rheostat to the home position when field-resistance is all out opens the switch and disconnects the dynamo. In starting the dynamo, when the dynamo voltage equals the lamp voltage, the first motion of the rheostat closes the switch and connects the dynamo and storage-battery together. A further rise of voltage causes the lamp-resistance to be inserted step by step between the battery and lamps and the battery begins to receive its charge.

The lamp-resistance is snown more clearly in diagram of connections in Fig. 4. The sections of this resistance are inserted as

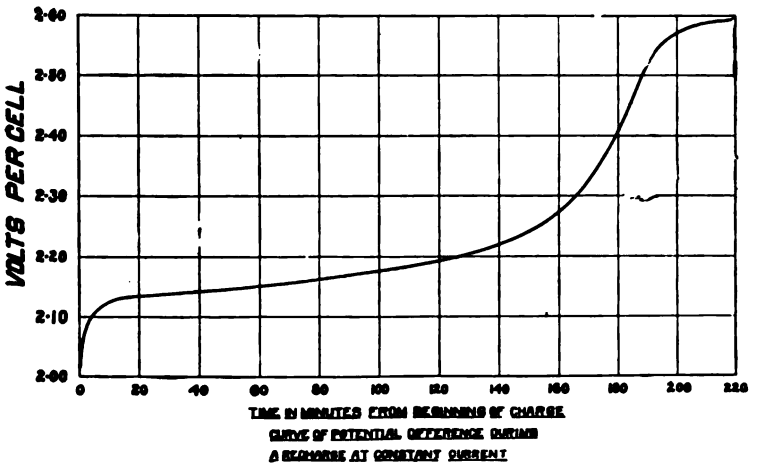


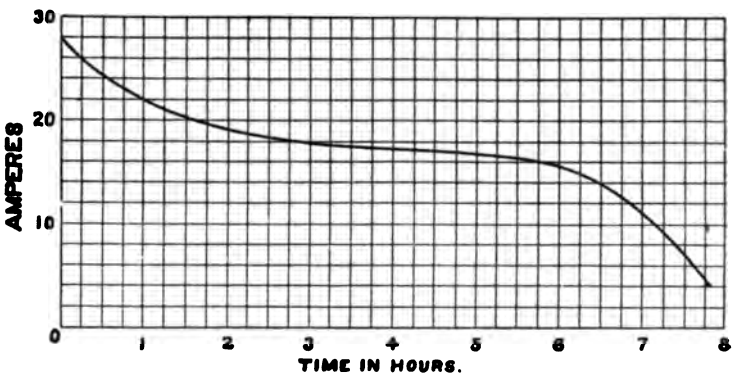
FIG. 6.

the voltage of the dynamo rises, causing motion of the rheostat-arm from its home position. The proper fall in voltage from that required for the storage-battery to the lamp-voltage is thus obtained. The lamp-voltage is that which the storage battery is capable of maintaining when the dynamo is not in operation. As the lamps are divided into two circuits, each circuit has its own lamp-resistance, which is inserted step by step by the rheostat-arm.

Vestibule-lamps are provided so as to give an abundance of light upon the steps and in the vestibules of a car when the train comes to a standstill. These lamps are preferably connected across the cut-out switch separating the dynamo from the storage-battery. The current for the vestibule-lamps therefore flows

from the storage battery through the dynamo and lamps in series. These lamps are lighted solely by the difference of the electromotive force of the dynamo and storage-battery. They are, therefore, lighted automatically when the speed of the train drops below twelve miles per hour, and come to full intensity at very low speeds and during stops. As these lamps do not draw upon the lighting apparatus during long runs, they can be made of ample intensity to furnish an abundance of light over the steps of a car at the time when the steps are in use, and at the same time do not draw upon the lighting apparatus at times when the lights in the vestibules are not needed.

The motor of this regulator performs a series of operations in a pre-arranged order. In the act of stopping a train, the rheostat



CURVE OF CURRENT DURING A RECHARGE OF STORAGE BATTERY UNDER A MODIFIED CONSTANT POTENTIAL DIFFERENCE.

FIG. 7.

moves to its home position and cuts out the resistance in series with the field-coils of the dynamo. As it approaches the home position it cuts out the lamp-resistance and automatically changes the tension of the regulator-spring to change the adjustment of the regulator from the voltage of the dynamo when charging the battery to the voltage of the lamps. When the dynamo voltage reaches the lamp voltage, the motor opens the switch between the motor and storage-battery. A further movement of the motor opens up its own circuit so that when the car is at a standstill there is no circuit through any part of the regulator or dynamo through which the current of the storage battery is wasted. However, all parts of the regulator are then in proper position, so that when the dynamo current picks up and excites

the solenoid, the effect upon the plunger is: first, to re-establish the circuit through the motor which is done at the carbon contacts; secondly, to close the circuit between the dynamo and storage-battery and then thirdly, upon a further rise of voltage of the dynamo, to cause the regulator to insert resistance in series with the lamps and in series with the field-coils of the dynamo.

In this regulator no motion of any of its parts takes place except when necessary to meet some change in the conditions of the lighting system. When the train is running at a constant speed the regulator is motionless. When speed increases, a slight motion takes place just sufficient to introduce the proper resistance in series with the dynamo fields to maintain the voltage constant. In this way we obtain the smallest wear of mov-

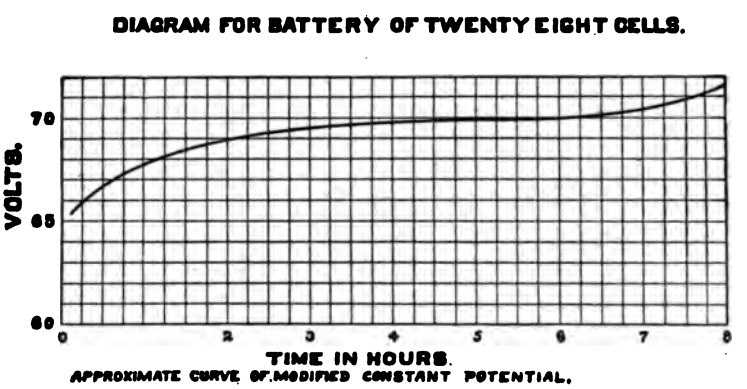


FIG. 8.

ing parts and the least possible care is required to keep the mechanism in order.

I have already referred to the fact that the regulator is controlled by a compound solenoid. I will now explain more in detail the construction and connections of the compound solenoid and the reasons for its use. By reference to Fig. 4 it will be seen that the compound solenoid is made up of two coils, one a large shunt-wound coil connected between the dynamo mains, and the other a small series-coil which is connected between the main and the storage-battery. These two coils act in conjunction when the dynamo is supplying current to the storage-battery and are opposed to each other when the storage-battery is giving out current. The compound solenoid draws the plunger against the tension of a spring. A motion of the motor always takes place

when the pull of either the solenoid or the spring predominates and causes the carbon contacts to close the circuit through the motor. The total of the effects of the two coils upon the plunger is equivalent to the tension upon the resisting spring.

Now, it must be evident that when the storage-battery is nearly depleted the rush of the charging current into it through the series-coil will cause the series-coil to increase its pull upon the plunger and hence reduce the voltage at the terminals of the shunt-coil. In this way the excessive flow of current into a depleted battery is prevented. However, as the charging operation proceeds and the counter-electromotive force of the battery increases, the decreased flow through the series-coil to the battery will decrease the magnetic effect of the series-coil and the voltage at the terminals of the shunt-coil will correspondingly increase. As the counter-electromotive force of the battery continues to increase, the decrease in the flow to the battery will slowly but gradually cause a rise in the voltage on the mains. When the battery begins to gas and the voltage of the battery rises abruptly, the shunt-coil will assume almost the entire control over the regulator and the current through the series-coil to the battery will diminish to not over 5 to 10 per cent. of the original charging rate, this being deemed just sufficient to cause the battery to gas slowly and replace battery losses or leakages. In this condition the apparatus may be used on a car having a daylight-run and with practically no load upon the dynamo after the battery has become fully charged. It is also used, without re-adjustment, upon cars operated wholly at night with all lights in use. It will be seen that with this simple device the charging of the storage-battery is made automatic and by proportioning the number of ampere-turns of the series and the shunt-coils the charging rate may be made to follow any formulæ that the battery-maker may prescribe. It will also be seen that with this method of regulation, we avoid the dangers of both the shunt and the series methods of regulating the charge to the storage-battery.

To show what these dangers are, I reproduce from a work on storage batteries by E. J. Wade, a curve of the current to a storage battery under constant potential-difference. (See Fig. 5). The heavy and destructive rush of current to the depleted battery is followed by such a reduction in flow as to render the completion of the charge difficult. Evidently the trouble here is too great a rush of current to the depleted battery and not sufficient current as the battery approaches full charge.

I here reproduce from the same book a curve of the potential-difference of a battery charging with a constant current. (See Fig. 6.) You will here notice the abrupt rise of voltage as the battery becomes fully charged. This is so abrupt that it would be dangerous to operate incandescent lamps on the same circuit. In Fig. 7 you will find a curve of current to a storage-battery as supplied by the apparatus described in this paper. In Fig. 8 the extent to which the constant potential is modified is also shown. In this apparatus, we avoid the danger of the shunt method by reducing the charging rate to the depleted battery and by increasing the charging rate as we approach complete charge. We avoid the danger of the series or current method of regulating the charge to the storage-battery by giving the largest rate of current when the battery is depleted and by avoiding the too-high charging rate of the series method when the battery charge approaches completion. When the battery begins to gas, we also avoid the abrupt rise in voltage of the charging current. We also avoid the danger of continuously charging a battery at a normal rate long after the charge of the battery has been completed.

BRANCH DISCUSSIONS.

DISCUSSION AT MINNEAPOLIS, MARCH 6, 1903.

During the reading of the paper on "Some of the Problems of Electric Train Lighting," Mr. Shepardson described the Gould system of axle-lighting, which had not been represented in the papers, noting its development from the Stone system, which is largely used in Europe. The dynamo is thrown into or out of circuit by a centrifugal governor on the armature shaft, which operates at a definite speed. Regulation is obtained by mechanical means, the adjustment of the belt being such that it delivers any desired torque to the armature shaft and slips if the peripheral speed of the driving pulley exceeds that of the driven pulley, which would cause the armature to develop more than the desired current at the desired voltage. Careful selection of materials for the belt and the pulleys secures the unusual result that the slipping occurs on the larger driving pulley rather than on the smaller armature pulley, thus localizing the heat developed from slipping at the car-axle pulley, where there is a large surface for cooling. Adjustment for any desired strength of current is secured by changing the tension on the belt. In practice there is found to be considerable variation in the belt tension when the car is rounding curves, for the dynamo is mounted on the car body and its spring suspension does not entirely prevent wide variations in belt tension when the car-truck swings. These variations in the current are absorbed by the storage battery, so that the voltage is sensibly constant.

Attention was called to tests upon the Muskowitz system formerly used on the Santa Fé road, in which the dynamos had a triple field-winding; a high resistance connected across the battery for the purpose of insuring prompt excitation, a second winding connected in shunt with the armature terminals, and a third winding in series with the armature, but connected so as to oppose the two shunt windings. The combination of the three windings was supposed to secure constant current and constant voltage for any train speed above that at which the dynamo was thrown into service. A series of tests by students of the University of Minnesota developed the fact that close regulation was actually secured by slipping of the belt as well as by the differential winding, thus classifying it in principle with the Stone system.

Discussing the costs of various methods of lighting, data were quoted from the records of one of the large railroads which had had long experience with different systems, showing the cost of lighting a 60-foot coach with 262 candlepower 5 hours per day and 365 days per year, to be as follows:

Oil	$113.43
Acetylene, gas generated on the car	236.05
Pintsch gas, equipment bought, gas made by R. R.	262.04
Pintsch gas, equipment bought, gas bought	246.35
Pintsch gas, equipment rented, gas bought	309.75

Storage battery, charged at terminal stations ..... 256..87
Dynamo and engine, full storage battery auxiliary ..... 254..68
Dynamo and engine, Pintsch gas auxiliary ..... 315..29
Dynamo and engine, oil lamp auxiliary ..... 194..51
Axle system no auxiliary..... 268..70

In justice to the axle system, it should be stated that this company has only a very limited number of axle-lighting equipments, no two alike, some operating under unfavorable conditions, some much more expensive than others.

Another large road which has a larger number of axle-lighting equipments in service, reports an expense of 18 cents daily for labor, which with 5 per cent. interest and 5 per cent. depreciation and $4.00 per month for power, makes a total of $13.00 per month or $156.00 per annum for the axle system. If longer experience justifies the latter figures, the axle systems can compete with every other lighting system, except possibly oil, on the basis of economy. Considerations of safety, independence, convenience, comfort and absence of disagreeable features should leave little doubt as to the best system of lighting.

DISCUSSION AT PHILADELPHIA, MARCH 9, 1903.

CHAIRMAN CARL HERING:—As the three papers on Train Lighting are very much alike, I think it would be better if we had all of them read before beginning the discussion. This is the method usually practised at the New York meetings of the INSTITUTE; unless there are objections, I shall call upon Mr. Bliss to present his paper first.

Mr. Bliss then read his paper. (See page 133.)

CHAIRMAN HERING:—In the absence of the other two authors, Mr. W. C. L. Eglin has been so kind as to abstract their papers. Mr. Eglin will please present these abstracts.

Mr. Eglin read abstracts of the papers by Messrs. Farnsworth and Sperry.

CHAIRMAN HERING:—The matter is now open for general discussion. There are some gentlemen here who have had experience with these systems. We would be very glad to hear from them. May I ask Dr. Dudley to say a few words.

DR. DUDLEY:—I am as deeply interested, I think, as any one can be in the successful lighting of railway cars by electricity. I worked very hard at it in connection with the Brush Company and their expert during 1882 and following. I am frank to say to you, however, as a result of a good deal of hard work and some failure, that I am just a bit skeptical even yet as to whether we will be able to solve this problem. I don't want to be a wet blanket in any shape, but the difficulties have been discussed before, somewhat, and in talking with Mr. Wood, electrician of the road, a few days ago, I found that though he, like most electricians and like most others who are dealing with nature, was very enthusiastic a year or two ago, he is less enthusiastic to-day. Three plans for

railway car lighting have been mentioned as feasible. First, storage batteries alone. That is what we used in 1882. We called it the transfer system. We used two batteries; one off, the other on the car, and each battery large enough to light the car for a definite period of time. We charged one at the station, while the other was used on the car. Since that time we have been charging a battery at Jersey City and one at Chicago. At one time we were inclined to believe that this plan would be entirely successful, because it is possible to fit a car with enough battery power to light it for any given run between Jersey City and Chicago, and then take it out and put another battery in its place, and so operate continuously. The storage battery has progressed materially since the day we began, but, I think that any man who has to do with it will wish it was a better apparatus. So much for the storage battery. The second plan is the generation of electric current by the movement of the car. That has already been discussed and we are hoping for a great deal from the device described. The third plan is a system now and for quite a time past in use on the New York and Chicago Limited, namely; an engine in the baggage car operated by steam from the locomotive, a dynamo in the car and storage battery under the car. A fourth system is also being studied; that is, putting some sort of generator on the locomotive. A generator operated by a steam turbine has been suggested and is now being experimented with at Albany. Some years ago we used to say that a car must be self-contained for three things: For its light, for its heat and for its ventilation. As you doubtless know, in the progress of time the heating has been made a train unit. In other words, we heat cars by steam taken from the locomotive, and the independent car heater has been superseded. It is possible that we may make the car self-contained so far as lighting is concerned by an axle-driven device. Besides experimenting with axle-driven devices, the tendency is toward making the train the unit, generating the current on the locomotive itself. I am sorry not to have any positive data to give you regarding the operation of some of the axle-driven devices. You are doubtless all familiar with the very serious difficulty of trying to operate by means of belts. As far as experience goes, that is almost insurmountable. The device Mr. Bliss described we regard as the best we have ever seen and the best we have ever experimented with.

I noticed in Mr. Sperry's paper something in regard to costs. If I have read it rightly, Mr. Sperry makes out that the electrical lighting of the train is considerably cheaper than other methods of lighting. Now, it is desirable to make a distinction. We do not calculate the cost for lighting by the same method that he calculates it. It is a question of lighting the car and not a question of cost per candle power per hour. If you light a car with an arc lamp you can generate your light per candle power per hour for probably a tenth of what it costs by any of the present

systems. But the distribution of the light is an essential feature. and an arc lamp is hardly a good light to have in a car. Mr. Sperry's figures are based on the cost per candle power per hour. We light our cars, approximately, with gas, giving a total illumination of one hundred and fifty candles, and with electricity possibly two hundred to two hundred and fifty—maybe more—Pullman cars a good deal more. If we consider candle power per hour, electricity comes out ahead. If we consider car lighting per hour, we find the gas system a good deal cheaper. We had a long discussion over this some months ago and I might have brought some figures showing the relative cost of lighting a car an hour by different systems; but as my memory serves me, it costs considerably more to light a car per hour with a fairly satisfactory light—not all the same candle power, mark you—but with a very satisfactory light, by means of electrical devices, than by gas.

CHAIRMAN HERING:—I would like to ask Dr. Dudley whether the unit is the same in the two cases? You say it costs more to light by electricity than by gas. Do you base that on the number of candles being the same?

DR. DUDLEY:—No, you can't do that. I tried to make that clear.

CHAIRMAN HERING:—But any other comparison is unjust

DR. DUDLEY:—Suppose you have a thousand cars to light, how much will be your bill for lighting? That is the problem the railroad man has to look at—how much for car lighting this year? You light your car with any kind of light that is satisfactory You can put in double light and the cost per unit will be cheaper but the total amount for car lighting will increase.

CHAIRMAN HERING:—It seems to me that must necessarily figure out. When you light them electrically you have a great deal more light.

DR. DUDLEY:—We agree to that.

MR. BLISS:—There is nothing at present that we know of that is perfect. Some things are better than others, and in bringing out a new thing it is simply necessary that it shall be better than that which it superseded. Dr. Dudley says it would be very cheap to produce light in a car from an arc lamp, per candle power per hour, but that the distribution is a question that cannot be lost sight of. That is admittedly true, but it is not perfect distribution that we have to compete with. We simply have to compete with gas, and we all know that the distribution of light in a car by gas is anything but ideal. The eaves and flies of the car, to use a theatrical term, are pretty well lighted, but the space occupied by the passengers is not well lighted, and the distribution, while its value cannot be reckoned in dollars and cents, nevertheless exists; and when electric light is produced even at a greater total cost than gas, it still has to be borne in mind that the value of the distribution that has been introduced tends to reduce the actual cost of the light per unit. In a Pullman

twelve section sleeper, the maximum available candle power, with the largest gas outfit ever installed, is about three hundred and fifteen candles. This is taking gas at twelve candles per cubic foot, which is rather high, or sixty candles per five cubic feet, which is the standard with the gas makers. But three hundred and fifteen candle power is not sufficient to light a sleeper or parlor car. With such a system as we have attempted to develop, the available candle power is about six hundred and forty. Not only is the candle power more than double, but the distribution should, in a measure, tend to reduce the actual cost of the lighting, if the quality of the light is a factor. It is very difficult to build this electrical apparatus small enough, so that when fully loaded it will give little enough light to be comparable with gas. The conditions of operation and the dimensions and construction of the truck make it rather difficult to build a very small machine.

To light a coach as it is lighted at present, a machine ought to be about one-third of the size of our generator, consequently the machine we turn out to-day is really too large for a coach, if that coach is not to be lighted any better than it is by gas. As a matter of fact, a coach can be lighted so brilliantly that it will look absurdly different from the gas-lighted coaches in the same train, and make an unfavorable contrast, and it may be, for this reason, that the railroad people may not wish to put so much light in a coach. We could not build a generator on the lines we have adopted, very much cheaper if it was designed simply to do less work. There are certain dimensions that fix the size of the machine. For instance, the driving gear is dependent upon the size of the axle, and this fixes the other dimensions.

MR. POPE:—Would we not meet Dr. Dudley's contention by distributing the light over more cars. I think Dr. Dudley suggested in the early part of his remarks that possibly the axle system might take the place of the single generator in the baggage car? Can you light two or more cars from the generator as it is now?

DR. DUDLEY:—I will only say that if we were perfectly satisfied with the present gas system we would not go into a new device. We are not satisfied; we want a good deal better light and we expect to pay for it. In answer to Mr. Pope, the idea of having every car lighted from the generator is absurd, if he will excuse me for saying so. The car has got to be a car. It has got to have certain things self-contained in it. We cannot often make up trains as we like. I have seen local trains going out made up of four combination cars. You understand what a combination car is. It was simply impossible to get the other cars in in time to make schedule. Every car must have its own light or whatever is essential for its production and operation.

CHAIRMAN HERING:—If Dr. Dudley will favor the Secretary with the data covering his experiment, he will be very glad to publish it.

MR. POPE:—I wish to explain, Mr. Chairman, that my remarks are due to Dr. Dudley's statement, that originally a car was self-contained, as regards its heating, ventilation and light. But we had got beyond that. The train was the unit now, and therefore the lighting system might be installed in a baggage car. For that reason I asked whether this was a possible development.

DR. DUDLEY:—I see the point. The only train equipped with the lighting system in the baggage car is the New York and Chicago Limited. Its cars are always kept together in the same train With the ordinary passenger coach that is not true, and the main line of the Pennsylvania is not operated that way. The car must be available for various kinds of passenger service, especially in local traffic. We cannot have, transportation officers tell us, certain cars assigned to certain trains. There are a few run between Broad Street and Jersey City that are made up of the same cars and come back the following day, but for the bulk of the local traffic we have to use any car that is available when a car is wanted.

MR. POPE:—I was not alluding to your electric lighting of local trains. I don't think I shall live long enough to see that. Any old thing will do as far as that goes.

CHAIRMAN HERING:—Are there any storage battery engineers here to-night? Is Mr. Lesley here, of the Storage Battery Company? Perhaps Mr. Lesley will tell us about storage batteries.

MR. LESLEY:—We are probably the firmest kind of believers in the storage battery car lighting used since 1882. We have had personal contact with them since 1888. We feel that the battery is now a thoroughly commercial article, and used in connection with the Bliss system, I think that the railroad people will find them all that can be desired. Batteries used in train lighting see very much more severe service than those used in stationary work. I believe the railway people thoroughly understand that and make the necessary allowances. The batteries used for train lighting are especially designed for that kind of work. I do not know that I can say any more. I am ready to answer any questions.

CHAIRMAN HERING:—Have you any data concerning the life of batteries used in this way?

MR. LESLEY:—That depends very greatly on the use of the system. We have batteries in use on the Atchison Road which have been in four years, if not five. The boxes are not in so good repair as they might be. Out in Arizona the temperature gets up to one hundred and thirty. We all know that high temperatures are not conducive to the best service from a storage battery.

CHAIRMAN HERING:—What system is used in that line you speak of?

MR. LESLEY:—The consolidated system. It has been in use now since 1894 or 1895.

CHAIRMAN HERING:—Is that an axle-drive system?

MR. LESLEY:—Yes; the axle-drive system with controlling devices, slightly modified from those originally used. They had two batteries in service alternately, now they have one battery.

CHAIRMAN HERING:—Is Mr. Woodward of the Storage Battery Company here?

MR. WOODWARD:—I think there is hardly anything I can say of interest on this subject to-night. My work is largely on the other side. I do not know that there is anything I can add at all to what Mr. Lesley says. If there is any question I could answer in any way I would be very glad to do it.

MR. HEWITT:—What kind of plate do you use now?

MR. WOODWARD:—For car lighting the plate used now is Manchester type of positive—somewhat similar to stationary battery work.

MR. HEWITT:—Has that road made any comparison between gas and electricity?

MR. WOODWARD:—That I don't know.

MR. HEWITT:—What is the size of those plates?

MR. WOODWARD:—About seven inches square.

MR. HEWITT:—What is the weight?

MR. WOODWARD:—That depends. There are two or three sets of batteries used for that equipment—nine, eleven and fifteen plate cells. I do not know the exact weight.

DR. DUDLEY:—It might be interesting to ask some of the storage battery people if they would be willing to guarantee the life of storage batteries. The duration of the battery is quite a large element in the cost. In our calculations the rapid deterioration of the battery was quite an important item. We will assume that the train arrives at Altoona and has more cars than passengers over the next division; then it is deemed advisable, for transportation reasons, to take a car out and it is put on a side track. Some of these cars may stand idle for quite a period of time; they may stand two weeks without getting into a train at all. Now, the deterioration under those conditions is somewhat greater than in daily service; yet it is an essential condition that a car must necessarily stand. The battery undoubtedly has been improved very greatly by the efforts of men here to-night, within the last five or six years. In our first work the life of a battery was very short. A year was about as good as we could get, even with an old Brush battery. It would be interesting to know the guarantee that could be used as a safe figure in estimating on the cost of car lighting where the battery is the element.

MR. BLISS:—A storage battery is really not a bad thing. We have all been interested in the announcements that Mr. Edison has made from time to time of what he is going to do in the battery line. But even he is on record as having once said, when he was asked what he thought of the storage battery, "Well, the damned thing is wet." That is the greatest drawback—being wet. It

does slop a good deal, which not only produces deterioration in itself, but produces a good deal of deterioration in other things —principally the metal work of the containing boxes in which the batteries are held, men's clothing and their anatomy. But a storage battery, when properly installed on a car and covered (and the cover need not be especially tight fitting to keep down the little slopping that may occur) does not give very much trouble; but where batteries are handled, as Dr. Dudley described in the transfer system, there is a great deal of trouble. At Jersey City, in the yards of the Pullman Company, where batteries are handled continually, the continued slopping and shaking of the batteries, as they are carried over tracks from the battery house to the cars, produces deterioration in the battery which is really excessive. It seems to me it can easily be avoided. In some kinds of work, a storage battery gives a great deal longer life and a great deal more satisfaction than in others I presume the most severe service to which a storage battery is ever subjected is that on an automobile, where the radius of action is guaranteed at fifty miles, say, and the owner is glad when he gets twenty-five. The storage battery is loaded up and then it is drained down, which means a very severe service; and this, combined with the jolting and vibration, and the non-professional care it oft-times receives, runs up the depreciation.

We all know that the central station battery does not depreciate, for two reasons: First, because it stands still, and is not allowed to slop about; and secondly, it is never charged to its utmost capacity and never drained out clear to the bottom. The same is doubtless true in car lighting. A car is not such an extremely rough place to carry a battery as you might suppose. I have seen storage batteries on railroad cars that are continually covered with railroad dust, where the presence of a drop of acid would be instantly noticed, yet those batteries would be just as dry as a chip for months and months. No particular trouble from slopping was discernible, and if batteries are used—not as straight storage batteries, being charged to the utmost and discharged to the limit, as in an automobile, but are operated in connection with some kind of generating system, either a steam engine and generator in the baggage car, or an axle system, provided the axle system holds together and does its work—the batteries will give satisfaction and show very good life.

I can relate one specific incident that will illustrate this point. I was operating a car on the Congressional Limited, the battery being furnished by the Pullman Company. Unknown to me, Mr. Sloan, the electrician of the Company, found it advantageous one day to appropriate this battery for use on another car. Not to leave me in the lurch, he improvised a battery made up from material that had been condemned and thrown on the scrap heap, and put it on the car I was trying to operate. I didn't notice it until about two months after, when he came to me one day and said: " I played a trick on you not long ago, giving you

this scrap. I have examined it and I see you have formed it up into pretty good shape. I shall let it stay." Railroad service is not hard, provided the batteries are not subjected either to rough handling or too excessive discharging or overcharging, and, above all, are kept dry and clean.

MR. EGLIN:—I have listened to Mr. Bliss' paper with a great deal of interest, particularly as four years ago I had occasion to investigate axle-lighting systems. At that time Mr. Bliss' system had not been produced. In going into details I found that over 90 per cent. of the trouble encountered was in the drive. In the early days a belt drive was used, the belt being driven on two flange pulleys; the theory being that the flanges would keep the belt on. As a matter of fact, however, the flanges seemed to be the source of trouble, as the belt would ride up on the flange and tear. After abandoning the flange pulleys, we had better results.

The records on the road that I was interested in investigating covered a period of more than a year at that time, and they had tried every conceivable form of belt without success. On every trip on this particular train at least one belt had to be renewed. The life of a belt was about six weeks or less. They carried a man on the train to look after the repairs, but his principal job was to put on belts. The comments of Messrs. Sperry and Bliss on the storage battery, applied at that time, too, because some batteries were old and useless. It seemed that their only function was that of acting as regulators. This particular system did not use boosters; it used rheostats. The field built up so quickly they had to have an artificial load to keep down the rise in voltage. I tried every conceivable way to upset the scheme in the electrical part. It worked perfectly except when the battery was cut out, when the e.m.f. jumped up to a hundred volts. It is evident that the battery is not the important part of the system.

The most important part of the axle system is in the driving and this seems to have received careful attention by Mr. Bliss. The question of electrical efficiency of the generator storage battery and electrical device is of secondary importance. The advantage of using boosters in place of rheostats for this class of work will not materially change the total efficiency, because the total power used per car is very small, and that is one of the important features—that it does not require any power at the time the train is being accelerated, as the generator runs free until the train attains a speed of eighteen to twenty-five miles per hour. The system of axle-lighting upon each car seems to me ideal, and would best fulfil the conditions of railroad service as each car is a complete unit and can be put into any train for any service. On the other hand, the locomotive is also a necessary unit to every train, so that the generator set could be made small enough to be put on the locomotive and be of such character as to require very little attention, for example, a steam-turbine set. The power for the lighting of the entire train to be supplied

from these generators, and batteries being installed in each individual car to supply the lights when the engines are being changed. This would place the minimum amount of work upon the batteries and place the electric generator and its drive in a much more accessible position and in a location where it would receive reasonable attention. With the developments of the steam-turbine which are now taking place, I think that this system should at least be given a trial.

The mechanical conditions of driving a generator under a car are exceptionally severe. First, on account of the danger of the ballast interfering with the belts—there are a number of cases on record where stone ballast has been raised from the roadbed and located between the belt and the pulley, cutting the belt. Secondly, on account of the large range of temperature through which a train may pass on a single trip, ice forming on the pulleys causing the belts to break or throw off. The cost of power of operating the train-lighting from the axle system has been demonstrated, the most important item being the cost of maintenance. The expenses could be divided into three heads: interest, depreciation and maintenance. The first is easily determined, and the second and third depend upon the care and forethought that have been exercised in designing apparatus destined to withstand so severe a condition of service. In the operation of 104 cars provided with the axle system, sixteen men were constantly employed in maintaining the system. It is evident that the entire cost was in this maintenance account. As almost two-thirds of this force was employed almost continuously in maintaining the driving device it is evident that if a suitable drive could be provided, either frictional or gearing, the cost of operating such a system can be materially reduced. At the time I made these investigations, proper allowance was made for maintenance account, and the cost compared very favorably with the lighting per car—not with the unit of candle power—which was charged at that time by the Pintsch Gas Company. These figures were based on throwing out a belt-drive and substituting a more satisfactory method. The question which Dr. Dudley stated, that the railroad company wanted an improved light seems to me a rational one. The old oil light was not discarded because gas was cheaper, but because gas gave a better light, and the Pintsch gas was substituted for the same reason.

The electric lighting of cars meets all the conditions from a lighting standpoint required by the railroad company. First, it is not affected by air current or changes in temperature; it can be placed in any location desired, and the current can be used for heating purposes or for motors. It is impossible to install gas berth-lights on account of the dangers of fire, and it is impracticable to operate fans with gas motors. The berth-light is an added luxury, and is much appreciated. Persons would rather ride on a train lighted by electricity than one lighted by gas. The question of actual cost of lighting would not deter a

railroad company from using an electrical system, provided they could place some reasonable value on the cost of maintenance.

The cost of maintenance of an axle-lighting system has been very heavy, but the railroad company has had no means of properly determining this as the manufacturer has generally maintained his own system. Considering that this system is twenty years old and until recently not fully developed, one cannot blame the railroad companies for moving cautiously. It is particularly gratifying this evening to see how far and how completely the mechanical features have been worked out, and I hope Mr. Bliss will have the success he deserves.

DR. DUDLEY:—There is one point I don't want to get away from, since we have storage battery people here. Is it, or is it not true that a storage battery, standing and not in use, loses current at such a rate that if it stands a considerable length of time the battery will deteriorate? Of all the passenger coaches that a railroad has, almost all of them are in maximum service for about seven or eight months in the year; three or four months in the year the equipment is not all used. What are we going to po with the batteries in those cars? With the gas system, if you leave the gas out a little bit you put more gas in and your system undergoes no deterioration, but if your battery is badly sulphated where are you?

CHAIRMAN HERING:—Will Mr. Lesley favor us with an answer?

MR. LESLEY:—Allowing that a battery is in reasonably good condition—and the batteries used in the axle-lighting system, as they are to-day, would come in in practically a charged state—it can stand a month without any serious amount of sulphating. If a battery is in the house longer than that, I would consider it advisable to have it charged at the end of the month, and I should think that could be easily arranged for in the shops. It is not absolutely essential, but advisable.

CHAIRMAN HERING:—Mr. Reed has had considerable experience with batteries; perhaps he will favor us with some remarks.

MR. REED:—I have never had any experience with train lighting. I have done some experimenting with the storage battery for many years. I have never yet run across a battery like that described by Mr. Lesley, which is all that could be desired. In fact, my experience with batteries has been just the reverse. If I could find a battery of that kind, I should be strongly tempted to try to infringe on it without having to pay damages. My opinion is that the point which Dr. Dudley makes in regard to batteries standing is pretty well taken. I think that a battery treated in that way does deteriorate. I gave up the idea some years ago of ever being able to get a battery that was all that could be desired, and since then I have been trying to get a battery that was very cheap so that it could be renewed at very little cost, paying less attention to trying to make it last a very long time; but so far I have not succeeded in getting a battery that inspired confidence.

CHAIRMAN HERING:—Mr. Eglin promised to give us an abstract of the discussion held in New York.

MR. EGLIN:—Mr. Chairman, the discussion this evening has covered most of the points that were brought out at the New York meeting, and I feel a repetition of them would not be of special interest, but there was one point brought out at the New York meeting which has not been touched on, which was that the best solution for the train lighting was to operate electrically the entire road; that is, if you are going to supply the lights electrically, why not operate the road electrically? This is a question for the future to discuss, and I did not think it belongs in this discussion.

MR. BLISS:—Of course electrifying the road and obtaining the light directly appeals to everybody as the ultimate solution; but if we gave a light that in any way compared with that of Brooklyn Rapid Transit, we would be requested to remove our apparatus.

MR. SPALDING:—I understand that on some railroads they use electric headlights. I think there is a unit of some kind placed on the engine back of the headlight, and the power is obtained from the engine itself.

CHAIRMAN HERING:—Can you say anything about that, Dr. Dudley?

DR. DUDLEY:—I never experimented except on lines east of Pittsburg. In many places the road is so crooked that if we had a million candle headlight it would not do any good, and so a headlight is regarded as a good sort of thing on a straight but not good on a crooked road that has many cuts. I have never seen them tried.

MR. KLUMPP:—The light spoken of by Mr. Spalding is a small generator and steam-turbine placed in front of the smokestack; the whole apparatus is not more than fifteen inches square.

DR. DUDLEY:—Where is that used?

MR. KLUMPP:—On several roads. It was written about in several papers lately. I do not know whether it is in the experimental stage or on the market now.

There being no further discussion, the meeting adjourned.

BRANCH DISCUSSIONS.

Discussion at Pittsburg, March 12, 1903

Programme:—

The meeting was called to order by Chairman P. M Lincoln, at 8.15 P. M.

The following papers were presented:

1. "An Electric Car Lighting System," by Wm. L. Bliss. abstracted by N. W. Storer.
2. "Axle Lighting," by Elmer A. Sperry, abstracted by B. B. Abry.
3. "An Axle Light System of Train Lighting," by Arthur J. Farnsworth, abstracted by S. M. Kier.
4. Resumé of New York Discussion, by Miles Walker.

The discussion was participated in by Messrs. P. M. Lincoln, J. S. Peck, N. W. Storer, A. H. Masters. B. B. Abry, J. M. Campbell.

Mr. Lincoln:—I note that Mr. Walker, in classifying the papers discussed at the New York meeting, divides them in two classes: Class 1, did not know anything about it; and Class 2, knew all about it but said nothing. I suppose if we were classified we would come under the first class.

Mr. Peck:—I think, after striving to follow through the diagrams of connection before us, we feel with Mr. Lockwood that no complicated system can live. I understand that Mr. Storer has a system which is extremely simple as compared with these, and if Mr. Storer is not in the hands of his attorneys we should like to have him explain his system.

Mr. Storer:—It is a great surprise to me to be called on in this way, but as my attorneys have not commanded silence I will give a brief description of a generator which I once designed for a train lighting system. It is, of course. in common with all the other systems that have been presented to-night, much better than anything else that was ever proposed.

The systems which have been presented here to-night remind me very strongly of the time I attempted to study out the connections of a well-known multiple-unit control system. There was such a maze of wires, connections, solenoids, etc., as almost to make one's head swim. This, of course, does not necessarily mean that the system would not work, for there is no doubt that a system, whether of control or train lighting, may work satisfactorily and still be extremely complicated; but it is an undoubted fact that the more parts there are in any system, the more likelihood there is for that system giving trouble. The great criticism which everyone must make on the systems which have been presented to-night is that they are very complicated. In this as in other branches of electrical engineering every endeavor should be made to simplify and reduce the number of parts.

The generator which I designed some eight or ten years ago

was a small 4-pole machine, designed to give a constant current of approximately 20 amperes and an electromotive force of approximately 50 volts over a wide range of speed, corresponding to a train speed of from 20 to 60 or more miles per hour. It was designed for gearing direct to the axle like an ordinary street car motor. The regulation of the machine was obtained in the same way as the regulation of the Westinghouse direct current arc generator system, which was introduced at that time. The field was separately excited and the armature reaction was so proportioned as to keep the current practically constant over a wide range of voltage, if run at constant speed; or a constant current over a wide range of speed if run at a constant voltage. The machine being connected to the battery terminals, the voltage was practically fixed and therefore the speed might change from the minimum at which the machine will give the battery voltage, to the maximum speed that the car will run, and the generator would still deliver 20 amperes. I may say that this system was never entirely worked out, as it was not thought advisable by the company with which I was connected to go into the train lighting business, at that time Consequently the matter was dropped. But the advantages which I could claim for this system are the inherent regulation of the generator, which I believe would obviate much the larger part of the automatic apparatus which is found in the systems which have thus far been presented. The fluctuations in voltage would certainly be very much reduced, as from the time the generator is cut into the circuit until it is cut out again, it will deliver a constant current. The minimum voltage would therefore be supplied when the generator is cut out of circuit and the battery delivering the entire current required. The maximum voltage on the lamps would be obtained when the load is reduced to a single lamp, and the remainder of the current used in charging the battery.

In any well-regulated system, the generator should not furnish much more current than that required for operating the lamps, motors, etc., which form its load. The battery should be charged, for the most part, at times when the load is off. Consequently, there need not be such wide fluctuations of voltage on the system, and there would be no use for the " bucker " or the series resistance.

The system described by Mr. Bliss is admirably worked out and will doubtless give excellent results over the range of speed for which it is adjusted, but there is too much apparatus. The system employing the series resistance must be placed in much the same class. Until Mr. Sperry's system is placed in operation, we must take his word for it that it is a perfect system. Personally, the lighting of the train from a single generating unit placed in the baggage car or on the locomotive appeals to me most strongly. The system is extremely simple and the apparatus is at all times under the control of an expert attendant. All

of the apparatus but the storage battery is removed from the car; the battery must be used to supply the lights when the car is cut off from the generator.

MR. MASTERS:—I am familiar with the system of car lighting adopted several years ago by the Consolidated Car Heating Company, of Albany, N. Y. No mention has been made of it tonight, possibly for commercial reasons. At that time this company had cars in operation between Albany and Montreal, on which they were experimenting. They took the same stand that has been taken here,—that complicated systems are not at all likely to succeed, and less likely from a commercial point of view than from any other.

There seem to be diverse opinions regarding automatic qualifications for the successful operation of an axle system. Viewing it commercially, I understand the Consolidated Car Heating Company to maintain that an equipment costing more than $700 or $800 would be objectionable to railway interests. They stated that so far as they were able to observe, the road for which they were then experimenting would approve any system that would not cost more than $800 per equipment. Complicated systems, involving many automatic principles, are, it seems to me, so expensive that they would probably not be considered at all.

Speaking about storage batteries, I think the same remarks hold good, not only in the equipment but in the maintenance of these batteries. Many arguments are advanced by the electric storage battery companies that their batteries are giving good life. My experience with storage batteries in the past has been that they do very well at start, but when you work them for transportation purposes, troubles arise which runs up the expense of maintenance very materially.

MR. ABRY:—I have been very much interested in the discussion of train lighting this evening. A comparison of the axle-lighting system with other systems and the disadvantages, particularly of the axle-lighting system, recall to my mind some difficulties we had to overcome in the measurement of speeds in some tests that we made on the Union Traction Company of Indiana. For measuring the speed, we employed a magneto-generator which was driven from the axle of the car by means of a belt. The magneto was first placed on a small platform, bolted to and extending directly out under the car from the yoke of the truck. This inclined the belt at about an angle of 45°. The results obtained were not very satisfactory. Finally, we suspended the magneto on a bracket still bolted to the yoke, but so arranged that the travel of the belt was nearly parallel to the track. We calculated the size of pulley needed on the car axle to give the required speed of the generator; this pulley was turned with a small flange and with a face slightly wider than the width of the belt, which was one inch. Upon making a trial run under these conditions, we soon found difficulty in keeping the

belt in place, and, as Mr. Walker said, there were belts all along the line. We found there was a lateral play in the car axle of two inches, more or less, besides the vertical motion due to irregularities in the track. The belt would not stay on. There was a continual tendency to climb over the flange of the pulley whenever the side play of the car axle became excessive.

We also had trouble at first with moisture softening the cement and the belt coming apart. We overcame the difficulty incident to the belt jumping by having a new pulley made with a flange about an inch in height, and the face of the pulley about twice as wide as the belt itself. After properly aligning the apparatus and mounting the magneto on springs, we finally obtained fairly satisfactory results.

The simple experiment of measuring speed on an interurban car seems to me to point very conclusively to the disadvantages of an axle-lighting system. I have observed on three of the principal roads of the West, the C. M. & St. P., the C. B. & Q., and I think the Santa Fe, the use of the system which is employed on the Pennsylvania Limited trains: viz., a generating unit with auxiliary batteries. In view of this fact, that system certainly must have some good features.

MR. CAMPBELL:—In general, it might be a good deal better to have a separate engine and generator in the baggage car, but what about lines where you have only a few cars electrically lighted? It would be out of the question to equip every baggage car or every passenger engine with a generator outfit of a capacity large enough to supply any combination of cars that may be attached to a train, for the sake of a few cars electrically lighted that may from time to time be used. Axle lighting is also preferable for a class of cars known as private cars or official cars, of which there are not a few. These frequently leave the home road and therefore should be self-contained, as it is not likely that all lighting systems would have the same voltage. On one road running out of Pittsburg they have the system discussed in Mr. Farnsworth's paper and the generator works very well. We had trouble for awhile with belts not staying on; they would get loose and slippy. That trouble was very largely overcome by changing the belt from a flat one to a V-shaped, short lengths of V-shaped pieces of leather are fastened to a flat belt and fit into V-shaped pulleys. These belts work well. We have had them last as long as a year, which seems a reasonable time. We found one trouble with the system; the adjustment of the main solenoid seemed somewhat delicate, but after being once set would maintain a nearly constant current. On cars running from 20 to 70 miles per hour, I have seen the current remain at about 32 amperes. The voltage does not remain altogether constant; it appears to vary more than 5 per cent. The resistance marked "E," in the diagram, seems to be too limited in extent, as a very short motion of the regulator cuts all this resistance in or out, with a consequent noticeable change in the lights.

MR. LINCOLN:—In discussing one paper, the question of expense was referred to, it being said that these systems would be too expensive. It seems to me that the public demands that trains should be electrically lighted, especially well-equipped trains. The fact that these complicated systems outlined here on the board have not only been proposed, but have been actually used, is the very best evidence that expense is not being considered.

DISCUSSION AT SCHENECTADY, MARCH 17, 1903.

Programme:—

The meeting was called to order by Past-President C. P. Steinmetz. The report of the Committee on Organization was read and adopted, after which the following papers were presented:

1. "Axle Lighting," by E. A. Sperry, read by H. G. Reist.
2. "An Electric Car Lighting System," by W. L. Bliss, read by W. I. Slichter.
3. "An Axle Light System of Train Lighting," by A. J. Farnsworth, read by A. H. Armstrong.
4. "Electric Train Lighting Problems," by George D. Shepardson, read by R. Neil Williams.

Prominent part was taken in the discussion by W. I. Slichter, A. H. Armstrong and C. P. Steinmetz. A communication after adjournment was submitted by R. Neil Williams.

MR. A. H. ARMSTRONG:—In the attempt to perfect the car lighting system, I believe many of the inventors have lost sight of the broad issue involved. I think that President Scott has touched on the right thing in proposing the substitution of electric locomotives for steam locomotives. By doing this the train lighting question is solved to the satisfaction of everybody. Many of our larger steam railway systems are seriously considering the electrical equipment of their lines, for local service at least, and in the east this local service extends over a considerable distance. In fact, the eastern travel consists of a series of local runs, and when once the question is taken up, it will not be too much to expect that the limits of local travel of neighboring cities should overlap and form a continuous electrified railway system, say from New York to Albany or from Jersey City to Washington.

All the papers read to-night advocate the car unit system involving some form of axle-driven generator and making each car independent of the composition of the rest of the train. This pre-supposes that the train will be composed of mixed Pullman and day coaches, the latter not being necessarily lighted electrically. Such trains, however, are more or less local in character and will be taken care of within a few years electrically, both for lighting and motive power. The through trains composed of similar units could either be lighted from third-rail shoes bearing

on third rail provided for local service, although hauled by steam locomotive, or else by a steam-driven unit in the baggage car or on the locomotive. This system is simpler and gets rid of the many complicated, even if ingenious, mechanisms proposed with the axle driven independent units.

To succeed in railway work a piece of apparatus should be capable of standing considerable abuse, infrequent attention, and should consist of as simple and few parts as possible. A steam turbine driven generator feeding a floating storage battery installed on each car sufficient to give light during times at station when train is broken up for a short time is much simpler, easier to take care of and possesses more promise of ultimate success than the complicated individual systems proposed. Moreover, it is in line with the future progress of steam railroad systems which are bound ultimately to equip their local traffic electrically, at least in the east.

MR. C. P. STEINMETZ:—While the papers read have been very interesting, I think it is to be regretted that no accurate information has been given about the extent to which such systems of axle lighting are being used: nor have we heard how many installations there are of a system of a separate constant speed engine driving a generator in the baggage car or on the locomotive. The phrasing of some of the papers rather leads to the suspicion that the systems described are somewhat experimental and have not yet stood the test of long-continued service.

After all, the amount of power required for train lighting is so insignificant compared with the power of the locomotive, that efficiency appears of very secondary consideration compared with simplicity and reliability. Any system starting from a source of power of such variable speed as that of the car axle necessarily requires a large amount of controlling apparatus to connect and disconnect generator storage batteries, etc., and can not possibly be as reliable as a plain constant speed, constant potential engine-driven generator.

I was very much pleased to find from the discussion that the only objection which fourteen years' experience had brought out against an old friend of mine, the Eickemeyer dynamo driven by a Brotherhood engine, was its large steam consumption. When a reciprocating steam engine running at 800 r.p.m., is left to the tender mercies of a baggage man for fourteen years and develops no other fault than high steam consumption it certainly represents a remarkable performance. Regarding all these here explained ingenious axle-driven systems, I question what would be left of any of them in practical operation under similar conditions.

W. I. SLICHTER —In the system proposed by Mr. Bliss the voltage of the generator is kept constant at a greatly increased speed by interposing a counter e.m.f. in the shunt field circuit. Thus, we may have three times full load speed, full load voltage, which would mean one-third field excitation, and there would be

a great tendency to spark. To obviate this, the dynamo must be either very large for its purpose or of a special design.

The low voltages used in all these systems is no doubt an aid to the long life of the lamps, since a low voltage lamp of a given candlepower can stand a greater variation in voltage in per cent. than a high voltage lamp.

On a general application of these systems, we know that the direct connected unit is used on one of the trains of the New York Central and the Gould system, in which an axle-driven generator charges alternately two sets of storage batteries, one of which is connected to the lamps while the other is being charged.

(COMMUNICATION AFTER ADJOURNMENT OF SCHENECTADY MEETING, BY R. NEIL WILLIAMS.

In reading the papers on Railroad Train Lighting, discussed at the March meeting of the INSTITUTE, I notice that it seems to be generally taken for a foregone conclusion that no system of electric train lighting is possible that does not entail the use of a storage battery. The experience we have had in the past with stationery storage batteries has not been such as to warrant our making them the all-essential feature of a train lighting system, where the continual shaking and jolting must shorten the life and reduce the reliability of the most up-to-date battery.

It is also difficult to see what advantages axle-lighting systems have over the large unit steam dynamo or preferably turbine-dynamo on the locomotive, where it properly belongs. In the former case we have as many units as the train has cars and we have all kinds of difficulties in transmitting our power from locomotive through drawbars to axles and from these to the dynamos, where further complicated devices are required to regulate voltage or speed under widely varying conditions. A simple flexible connection from car to car is certainly cheaper and gives the right power whether train is standing or moving.

Furthermore, the jar from a comparatively small collision would probably be sufficient to demolish any storage battery, whereas, even though all the cars should be completely demolished and only the locomotive left intact, or partly intact, it would be easy to rig up temporary lights from the engine. The following arrangement contains nothing new in the way of engineering features, but at the same time has not been brought out, as far as I know, as a possible and very simple solution of the problem and one which avoids entirely the use of storage battery.

This would be simply to have the cars wired as they are on any electric railroad, but without regulating devices of any description. The tracks would be used for return circuit and power led into the car and from car to car by a flexible coupling, energy being supplied from turbine-dynamo set on the locomotive. This would give light at all times except when the locomotive was uncoupled from the train, which, though occurring frequently is never at any other place than where there are

stations or at least switches and sidings of some kind. If, wherever there is a switch or siding of any kind, in fact at any place where there could ever be any object in the locomotive being uncoupled, a third rail were provided of very modest dimensions and each locomotive as well as each car were provided with a simple shoe, then whether coupled or uncoupled the engine would itself feed the third rail and from it the cars would receive their energy at the same voltage they had been receiving and under exactly the same conditions. There is no apparent reason why cars should be lighted until sometime before the trains are ready to start and then there will always be a locomotive in the neighborhood. Of course, with Pullman sleepers which take on their passengers in the early part of the evening long before the train is ready to leave, it might occur that there was no locomotive in the vicinity. In this case it might be necessary to have a stationary storage battery at such points floating on the third rail, but this would be the exceptional case, and even here the storage battery would not be jolted to pieces. The expense of this third rail, even if it were laid at every switch and siding from New York to San Francisco, and of the one shoe per car and locomotive, would be extremely small, compared with the expense of the storage battery and the divers regulating devices required, if we were to attempt to light all our cars by the axle system.

At this stage of engineering advance in America, it is a poor showing that the railroads make with their flickering gas light and continually re-occurring fires, and it would seem as though the time were ripe for revolutionary changes.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

HIGH-TENSION TRANSMISSION LINES.

INTRODUCTION BY PRESIDENT SCOTT.

The invention of the steam engine underlies the progress of the nineteenth century. Cheap and abundant mechanical power has been a prime factor in that advancement. The railroad, the steamship, the machine shop, the factory, the rolling mill, the modern printing press and the mine hoist are developments which are based upon the steam engine. If the coal supply be shut off, the whole mechanism of our modern civilization comes to a standstill. There have been two lines of development; one of the engine for producing power, the other of machines and appliances for utilizing power. On the one hand, the development has been toward engines of large output to secure highest efficiency, and on the other hand, its load of innumerable tools and machines has sprung up demanding power often in small units and sometimes at varying speed. The development of the engine and of the machines for utilizing power has been much more rapid than that of the appliances for transmitting and distributing power from the source to the consumption. All of the various agencies; shafting, belting and various types of mechanical, pneumatic and hydraulic transmission—the primitive methods of transmission—found their ready limitations in efficiency, in capacity or in distance. It was because it supplied this missing link so effectively that the electric motor and electric power distribution has had so phenomenal a development. Electric distribution is so far superior in point of flexibility, efficiency and effectiveness to other methods that it has superseded them except in the most limited fields. But the transcendent characteristic of electric transmission is its application to long dis-

tances. Compared with preceding methods of transmission electric distances are infinite.

Electric transmission in its unique and infinitesimal form has replaced the speaking tube by the telephone, and has given new possibilities to human speech. So, also, it has given to power development—the vital element in the industrial and commercial progress of the past century—possibilities of a new order. It not only transmits and conveys, but it has made available a new source of power—not beds of stored energy, but waterfalls of wasting energy.

The relation between distance and voltage is well known. The past ten or a dozen years have witnessed a steady advance in the voltages in commercial use. Additions from the experimental and undeveloped regions of high voltage have been conquered and brought into the domain of commercial service. The line between that which is practicable, and that which is indefinite and uncertain, has continually advanced. Each increase in voltage introduces new problems, reveals new classes of phenomena and presents difficulties more complex. Problems in construction and design and installation of apparatus; problems in insulators and line construction; problems in switching, controlling and measuring current; problems in lightning and static protection have been presented and solved with each advance in voltage. It has not been so many years since 100 or 200 k.w. to be transmitted 20 or 30 miles at 10,000 volts, was considered a somewhat remarkable undertaking.

The changes from the conditions of ten years ago to those of to-day have been, step by step, along the lines of scientific and engineering progress. The advance has been an evolution. The problems in transmission have been engineering problems, they have been far-reaching problems. Electrical theory, mathematical formulæ, the brilliant inventor, the skillful designer, the careful experimenter and the intelligent operator have all contributed to the continuous solution. Prime factors in the advance have been experience and the ability to interpret experience and make it the foundation for further advance. The purpose of the Transmission Committee of THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS is to utilize experience. Mistakes have been made; they have been overcome. Experience has demonstrated what is successful. There is no credit to the electrical engineering profession in reducing the efficiency of electrical enterprises by repeating mistakes. The responsibilities

which rest upon the profession call for the most efficient coöperation for the elimination of inadequate methods. We must crystallize through present practice that which should be made standard practice. We must make definite the steps already taken and lay the foundation for the future.

The progress in high tension transmission is indicated by the transformer statistics of one of the large manufacturing companies. Transformers for 10,000 volts and over have been built during the past twelve years. Units recently built have three times the output of the largest transformers of five years ago. The aggregate output has been over a million kilowatts. The average kilowatt output per month during the past year is equal to the total output during the first seven years. The output of the past two years has exceeded that of the preceding ten years.

I repeat that the transmission problem is an engineering problem. It is not a simple one. It is difficult; it is comprehensive; it is not a one man problem to be solved by some individual with a peculiar scheme. It is a problem for the engineering profession. It is one to which the engineers who operate plants, who use apparatus as well as those who invent and design must contribute. We must coöperate. After we have helped one another all we can there are still problems which will tax the most able and most active.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

MECHANICAL SPECIFICATIONS OF A PROPOSED STANDARD INSULATOR PIN.

BY RALPH D. MERSHON.

A mathematical consideration of the fibre stresses in wooden insulator pins and a recommendation as regards standard dimensions and methods of construction.

At present no general standard exists in the matter of Insulator Pins. As a result, there is often confusion and dissatisfaction in ordering and obtaining pins. This discussion of a proposed standard pin is intended to lead up to a general specification covering wooden pins, and, so far as it may, metal ones.

Theory.—The expression for the extreme fibre stress at any point of a beam of circular section fixed at one end and loaded at the other, as in Fig. 1 is

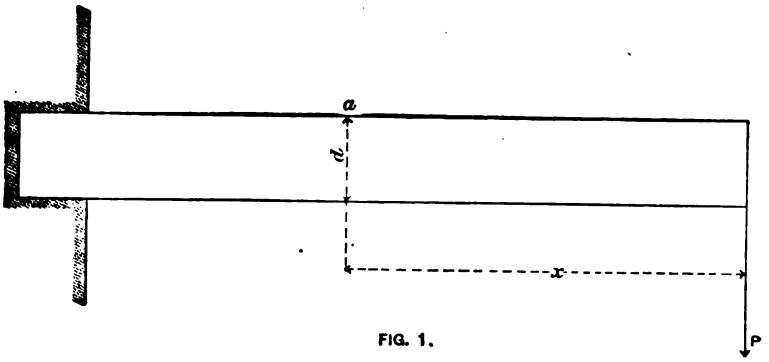


FIG. 1.

$$s = \frac{P x}{.0982\, d^3} \qquad (1)$$

where (assuming inches and pounds as our units) P is the pull or weight in pounds; x is the distance in inches from the point of application of P to any point a of the beam; d is the diameter in inches at the point a; s is the extreme fibre stress in pounds per square inch, *i.e.*, s is the stress on the extreme fibres at the top and bottom of the beam at the point a.

This equation shows that for a given pull P the fibre stress at any point a at a distance x from the point of application of P varies directly as x and inversely as the cube of d. It is possible, therefore, to design a beam of circular section whose diameter in passing from the point of application of P to the point of support shall vary in such a way that s will have the same value all the way along the beam. Such a beam will be of uniform strength throughout its length. The value which, in such a beam, d must have at any point distant x from the outer end may be found by assuming s and P constant in Equation (1) and solving for d in terms of x. This gives

$$d = \left(\frac{P}{.0982\,s}\right)^{\frac{1}{3}} x^{\frac{1}{3}} = K x^{\frac{1}{3}} \qquad (2)$$

where K is a constant whose value must be determined from the extreme fibre stress allowable with a given pull P. Equation (2) shows that in order to have the beam of uniform strength throughout its length, its diameter must vary as the cube root of the distance from the point of application of its load.

An insulator pin is the case of a beam of circular section fixed at one end and with a load (any side pull which may come upon it) applied at or near the other end. There is no object in having an insulator pin any stronger at any one point than at another. It should, therefore, in its capacity as a beam, be tapered as nearly as practicable in such a way that s will be constant throughout; that is, so that equation (2) will apply to it.

The point where pins usually break, their weakest point, is just at the cross-arm. The wooden pin most generally in use is one having a diameter of about $1\frac{1}{2}$ inches in the cross-arm and a length such that the wire is from 5 to 6 inches from the cross-arm. Let us obtain the value of K in (2) on the assumption of $d = 1\frac{1}{2}''$ and $x = 5''$. This gives the value of K as .877, so that, substituting, (2) becomes

$$d = .877\, x^{\frac{1}{3}} \qquad (3)$$

From (3) we may find the diameter required at any point in any length of pin, the pin to be of uniform strength throughout. Substituting various value of x we have the following:

x (inches)	d (inches)
1	.877
2	1.106
3	1.263
4	1.395
5	1.5
6	1.592
7	1.678
8	1.754
9	1.825
10	1.888
11	1.95
13	2.06
15	2.17
17	2.25
19	2.34
21	2.42

This table shows that for a pin having upon it a pull one inch above the cross arm, the diameter at the cross-arm must be .877 inches; that one having a pull upon it 10 inches above the cross-arm must have a diameter at the cross-arm of 1.88 inches, etc.

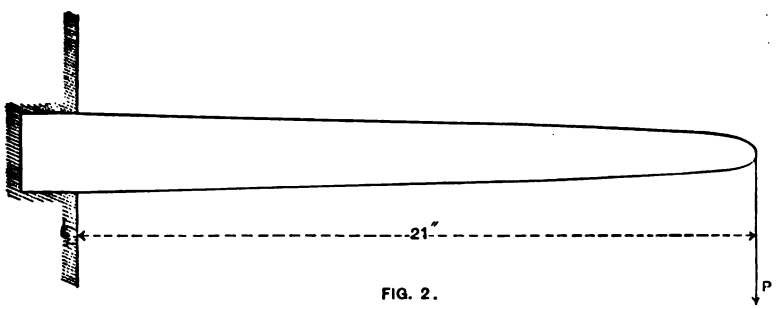


FIG. 2.

Fig. 2 is a sketch of such a theoretical pin drawn by platting the above values to a scale one-quarter of full size. Fig. 2 represents all sizes of pins up to and including one the pull upon which is applied 21 inches above the cross-arm. That is, if we want a theoretical 6 inch pin we must cut 6 inches off the end of Fig. 2 and use that; for a 10 inch pin we must cut off 10 inches, etc.

The practical pin must be a modification of the theoretical pin. The end must be square and a portion of the small end must be threaded. The pin must also have a shoulder just above the cross-arm. It will be noticed that, except near the end, the sides of the theoretical pin are practically straight. It will suffice, therefore, if in designing a pin we fix the diameter at the lower end of the thread portion and the diameter just above the cross-arm and make the contour between these points a straight line.

Threaded End.—It is proposed to make the diameter of the small end of the pin 1 inch; the length of the threaded portion 2½ inches; and the diameter at the lower end of the threaded portion 1.25 inches, so that the threaded portion will taper from 1.25 inches to 1 inch in a length of 2½ inches. The threaded portion of the insulator should have the same dimensions and taper as that of the pin.

Shoulder.—It is proposed to make the shoulder 3/16 inch on all pins. That is, the diameter of the pin just above the cross-arm will be ⅜ inch greater than the nominal diameter of that portion of the pin in the cross-arm; it is proposed to carry this diameter ¼ inch above the cross-arm before tapering the pin.

Dimensions in Cross-Arm.—It is proposed to make the diameter of that portion of the pin in the cross-arm, just below the shoulder, 1/32 inch less than the diameter of the hole in the cross-arm and at the lower end of the pin 1/16 less than the diameter of the hole in the cross-arm. It is proposed, also, to designate this portion of the pin as having a nominal diameter equal to that of the hole in the cross-arm into which the pin fits. Therefore, that portion of a pin which is to fit a 1½ inch hole in a cross-arm will have a nominal diameter of 1½ inch but will have an actual diameter just below the shoulder of 1–15/32 inch, and at the lower end of the pin of 1–7/16 inch.

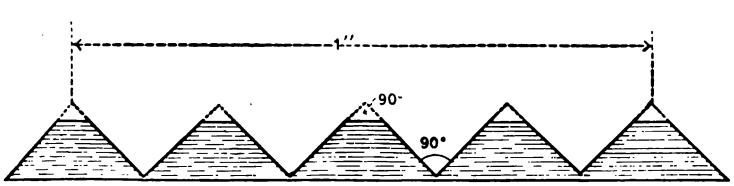


FIG. 3.

Thread.—It is proposed to use on all pins a thread having a pitch of ¼ inch or 4 threads to the inch, the form of thread to be that shown in Fig. 3 (scale three times full size). As there shown

the angle between the faces of the thread is 90° and the top of the thread is flattened by cutting off, from the form the thread would have if not flattened, one-fourth its unflattened depth. The form of the thread in the insulator should be the same as that on the pin. If this is done it will insure the bearing surface being always on the sides of the threads and never on the edges.

Designation.—It is proposed to designate that portion of the pin above the cross-arm as the " stem " of the pin. That portion in the cross-arm as the " shank " of the pin. It is proposed to designate a pin by the length of its stem, *i.e.*, a pin whose stem is 5 inches long will be designated as a " 5 " inch pin, one 6 inches long as a " 6 " inch pin, etc.

Dimensions of Standard Pins.—In accordance with the above the following table has been prepared, giving a number of sizes of pins, and their dimensions, which it is proposed to make standard. The diameter of the shank has in each case been fixed by making it approximately equal to (slightly larger than) the diameter of the theoretical pin corresponding to the length of the stem of the pin in question. The headings of the columns of the table refer to the lettering of Fig. 4.

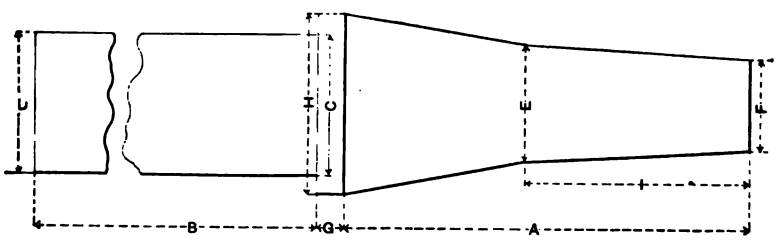


FIG. 4.

Size of Pin.	A	B	C Nominal.	C Actual.	D	E	F	G	H	I
5"	$4\frac{1}{4}$"	$4\frac{1}{4}$"	$1\frac{1}{2}$"	$1\frac{5}{32}$"	$1\frac{7}{16}$"	$1\frac{1}{2}$"	1"	$\frac{1}{4}$"	$1\frac{3}{8}$"	$2\frac{1}{4}$"
7	$6\frac{3}{4}$	$4\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{23}{32}$	$1\frac{11}{16}$	Same for all sizes of pins.	Same for all sizes of pins.	Same for all sizes of pins.	$2\frac{1}{8}$	Same for all sizes of pins.
9	$8\frac{3}{4}$	$4\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{27}{32}$	$1\frac{11}{16}$				$2\frac{1}{4}$	
11	$10\frac{3}{4}$	$4\frac{1}{2}$	2	$1\frac{31}{32}$	$1\frac{15}{16}$				$2\frac{3}{8}$	
13	$12\frac{3}{4}$	$4\frac{1}{2}$	$2\frac{1}{8}$	$2\frac{3}{32}$	$2\frac{1}{16}$				$2\frac{1}{2}$	
15	$14\frac{3}{4}$	$4\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{7}{32}$	$2\frac{3}{16}$				$2\frac{5}{8}$	
17	$16\frac{3}{4}$	$5\frac{3}{4}$	$2\frac{3}{8}$	$2\frac{11}{32}$	$2\frac{5}{16}$				$2\frac{3}{4}$	
19	$18\frac{3}{4}$	$5\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{15}{32}$	$2\frac{7}{16}$				$2\frac{7}{8}$	

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

THE TESTING OF INSULATORS.

BY F. O. BLACKWELL.

A statement of the requirements for satisfactory insulators and recommendations as to apparatus and methods of carrying on insulator tests.

An electric power transmission cannot be successful unless it is able to deliver uninterrupted power.

Continuous operation, so far as the transmission line is concerned, depends largely upon the effectiveness of the insulator which is employed. Insulators must, therefore, be obtained which will not fail in service and this can only be assured by the thorough testing of each one that goes on the electric lines.

The potential that can be employed safely for the transmission of power is now limited by the pressure the insulators will bear, as transformers that are reliable and not excessive in cost can be built for twice the voltage that any line yet constructed will withstand.

As the distance over which power can be transmitted with a fixed cost of conductor varies with the potential, the length of transmission lines is to a great extent limited by the insulator.

The design of new and improved types of insulators is, therefore, most important, and these can only be developed by experiment with adequate testing facilities. In order to ascertain the value of such insulators, no method of testing can equal a practical trial under conditions of actual service. Placing new insulators on power transmission lines in commercial operation is impracticable in most cases and should only be permitted after they have successfully withstood tests to demonstrate their

ability to stand operating conditions. These tests should duplicate as nearly as possible the electrical and mechanical strains set up in the insulators under the most severe conditions that would ever be met with on a transmission line.

There are certain facts which must be considered if correct deductions are to be made from insulator tests. For instance, we cannot test each insulator with a given number of volts continuously as it would be in service. As is well known, all insulating materials are most apt to break down on long applied electric stress. The prepared cloth wrappings used on the windings of electrical machinery will stand instantaneously two or three times the potential that they will carry continuously. Glass and porcelain are not affected by time to the same extent as organic materials, but we know that both kinds of insulators have been punctured by long continued applications of lower pressures than those which they have withstood in tests of short duration.

The shape of the potential wave also has a pronounced effect in breaking down insulation. A wave may be either flat topped or peaked, so that the maximum instantaneous potential is much less or greater than that of a sine wave of the same square root of the mean square potential. We might have for the same potential as read by the voltmeter, maximum instantaneous potentials which differ as much as two to one.

In air, the maximum point of the wave determines the distance which the current will jump. Different generators or even the same generator under different conditions of load will show widely varying arcing distances for the same potential.

Insulating materials being more affected by time than air, show in their ability to resist puncture that the average potential of the wave is more important than the maximum.

It is not safe to assume the potential either by the voltmeter or air gap as the true potential for determining the insulating value, as it is somewhere between the two. Moisture in the atmosphere also effects the arcing distance. In steam, a given potential will jump twice as far and in a fog 25 per cent. farther than under ordinary conditions. Of course, if the altitude is high and the air more rarified, the arc will also jump a greater distance.

I would like to call attention to the characteristics of the apparatus required for testing insulators.

The alternators generally used for long-distance transmission plants give very nearly a sine wave and therefore the testing generator should be one which will give a sine wave under all

conditions. It is not sufficient to do so at full potential and no load, as tests are made with all degrees of excitation and with both leading and lagging currents.

The armature reaction should be as small as possible, which means that the generator should be much larger than would ordinarily be thought necessary. It is also desirable to have a high reluctance in the magnetic circuit to secure stability when running with weak fields and permit of control with a reasonable amount of field resistance.

There should be but one transformer used to step up to the highest potential required and its reactance should be as low as possible. A number of transformers in series is particularly bad, as it gives poor regulation and leads to great uncertainty as to the actual potential to which an insulator is being subjected.

I have known testing sets with transformers in series and a generator of poor regulation to vary widely in the relation of the generator volts and the length of the spark gap due to change of wave form with different magnetic saturations of the apparatus and different numbers of insulators and consequently various capacities on the testing circuit. The only certain way to determine the real potential is to have a step-down instrument transformer on the high potential circuit.

Assuming that insulators are to be passed upon for a specific transmission plant, they should first be inspected to see that they are free from cracks, bubbles or pits that will impair their strength or in which moisture can lodge. If of porcelain, the glaze should cover all the outer surfaces. The glaze is of no insulating value in itself, but dirt sticks to unglazed surfaces.

Experience has shown that porcelain insulators which are not absolutely non-absorbent are worthless. The best porcelain shows a polished fracture like glass. If there is any doubt about the quality of the porcelain in this respect, it should be broken into small pieces, kept in a hot dry place for some time, weighed, and immersed in water for a day. When taken out of the water the weight should be the same as at first. A puncture test should be made by setting the insulator in a cup of salt water, filling the pin-hole also with water and slowly increasing the potential between the top and bottom until the desired test potential is reached or the insulator either punctures or arcs over the surface.

If an insulator is built up of several parts, each part should be able to withstand a pressure greater than it will have to sustain

when the complete insulator is tested. If it is to be tested for 100,000 volts and is made in two parts, each part might, for instance, be tested with 70,000 volts. The object of this is to have the weak parts rejected before they are assembled. A fair puncture test for an insulator is twice the potential for which it is to be employed, applied between the head and the interior for one minute. For example, the insulators for a 50,000 volt line should each stand 100,000 volts. As the potential from any wire to ground on a 5000-volt three-phase system would only be about 30,000 volts, a 100,000 volt test gives a factor of safety of nearly three and one-half to one. If one branch were grounded, as sometimes occurs in practice, the factor of safety would be but two to one. A one-minute test is not so severe as a continuous application of an equal potential, but insulators that have passed this test stand up well in service.

New types of insulators should be mounted on iron pins and tested both wet and dry, to determine the potentials which will arc over them. The dry test is of little value, as the potential at which the arc jumps from the head to the pin can be predetermined by measuring the shortest distance between them and referring to a curve of arcing distances in air. In a wet arcing test, a stream of water from a sprinkler-nozzle under a pressure of at least 50 pounds to the inch should be played on the insulator at an angle of say 30 degrees from the horizontal. This will be similar to the condition which exists in a rain and wind storm. The insulator should not arc over from the wire to the pin at less than the potential which will exist in service between any two conductors.

In no case should wooden pins be relied on for insulation, as their value is only temporary. All wooden pins in time become dirty, absorb moisture and eventually burn off unless the insulator is good enough to be used with an iron pin. If an insulator is going to fail, it is better to have it do so at the start and not interrupt the service by breaking down perhaps years afterwards.

In addition to the electrical tests, it is well (if the insulator is of a type that seems to require it), to try samples for mechanical strength. When mounted on pins the insulator should stand a side strain of at least ten times the pressure exerted by the air on the conductor with a wind velocity of, say, 100 miles an hour.

It should also be able to slip the conductor through the tie-wire should the former break.

These tests are particularly desirable with built-up insulators in order to be certain that the parts will not separate. With such insulators, it would also be well to test them in tension along the axis of the pin, as in transmission lines crossing depressions such an upward pull is not infrequently exerted on the insulator.

The above notes and suggestions are the result of the writer's tests of insulators, and observations of high potential lines. There are many members of the Institute whose experience has been wider and who have doubtless given the matter much thought.

It is the purpose of this paper only to touch briefly upon an important subject in order to open a discussion which it is hoped will bring out much valuable information.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

TRANSPOSITION AND RELATIVE LOCATION OF POWER AND TELEPHONE WIRES.

BY P. M. LINCOLN.

A consideration of the causes of electrical disturbances in telephone lines which parallel high-tension lines, and of means for reducing these disturbances.

(1) The extraordinary sensitiveness of the telephone receiver makes this instrument peculiarly susceptible to electrical disturbances. One authority states that the energy used in a sixteen candle power incandescent lamp is sufficient to produce an audible sound in thirty billion receivers. The methods, therefore of shielding telephone wires from the inductive effects of neighboring wires become important. Particularly is this true in the case of a telephone line paralleling a high-tension transmission line, where the inductive disturbances are apt to be large, and uninterrupted service on the telephone line important.

(2) The remarks and discussion in this " Introduction to Discussion " apply particularly to telephone lines paralleling high-tension lines, but comments hereon need not be restricted to such cases.

(3) There are three ways in which disturbing current in telephone circuits may be caused by the high-tension circuit.

(1) Electromagnetic induction.

(2) Electrostatic induction.

(3) Leakage.

It is the first two causes of disturbances which will claim particular attention in the following discussion.

(4) Electromagnetic induction may be briefly described as a transformer action. In Fig. 1 let *a*, *b* and *c* be the conductors of a three-phase line, and *m* and *n* the two wires of a paralleling telephone circuit. *a* and *b* may then be regarded as the primary and *m* and *n* as the secondary of a transformer. The e.m.f. in circuit *mn* will depend, among other things, upon the amount and frequency of the current in the inducing circuit. By transposing *m* and *n* in the well-known manner, the e.m.f.'s set up in one part of the telephone circuit will be neutralized by equal and opposite e.m.f.'s set up in other parts. Thus, the electromagnetic effects between *m* and *n* may be entirely neutralized by trans-

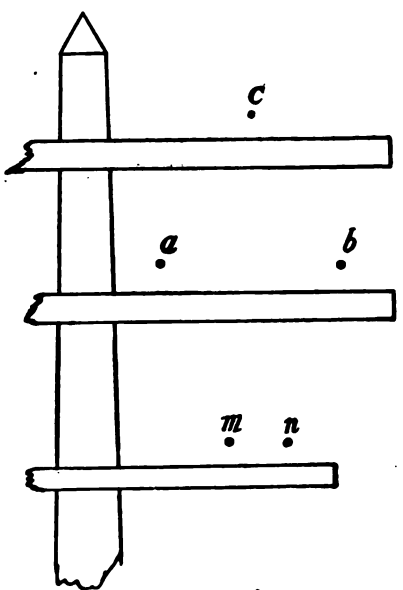


Fig. 1

posing the telephone wires only, regardless of whether the transmission wires are transposed or not. It may be well to note, however, that while the e.m.f. *between* the two telephone wires may be reduced to zero by properly transposing the telephone wires only, the e.m.f. between the two telephone conductors considered as one side of a circuit and the earth as the other, can be reduced to zero only by transposing the power wires. This point is of little importance, however, as any electromagnetic e.m.f. between the telephone wires and ground is entirely overshadowed by the electrostatic which will be considered later.

(5) Electrostatic effects will also take place in *m*, *n*, due to transmission circuit *a*, *b*, *c*. If conductor *a* has a minus charge

for instance, it will induce a certain plus charge on m and a smaller plus charge on n, on account of n's greater distance from a. If now the minus charge be removed from a, current will flow from m to n, proportional to the difference in the amounts of these charges. The electrostatic influence of b, being oppoite a in sign, will reinforce the action of a. Transposition of the telephone wires will have the effect of neutralizing this tendency of setting up electrostatic currents between m and n. It is important to note that a system of transpositions designed to correct electromagnetic induction between the wires will also be correct for electrostatic induction.

(6) Considering the comparative electromagnetic and electrostatic disturbances in a section of untransposed telephone line, it may be interesting to observe that the first is in the nature of a constant potential effect and the second of a constant current effect. It is evident that induced electromagnetic e.m.f. is constant as long as the inducing current is constant. As for the electrostatic effect, it is evident that the amounts of the induced charges on m and n, and therefore the electrostatically induced current between them, will not become appreciably reduced until the current flowing between m and n makes a difference of potential between them appreciable, compared with the inducing difference of potential. With telephone receivers of varying resistance, therefore, the ampere-turns in the receiver due to electromagnetic induction are practically constant, while those due to electrostatic induction increase with number of turns and therefore the resistance of receiver. The electrostatic and electromagnetic effect become roughly equal with an arrangement shown in Fig. 1, when a, b, c is a line carrying 50 amperes at 20,000 volts, and the telephone circuit contains a total resistance of 1,000 ohms, including receivers.

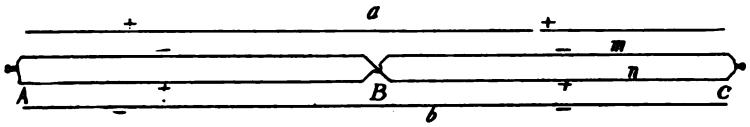


Fig. 2

(7) The bridged telephone has almost universally taken the place of the series instrument for all telephone work. The series telephone is particularly objectionable for use on a circuit in which static induction takes place to any great extent. The reason for this is seen by an inspection of Fig. 2. The telephone

wire *m* has between *A* and *B* a plus charge induced and between *B* and *C* a minus charge. There is, therefore, at the transposition point *B* a flow of current from one section of *m* to the other. If now a series telephone be placed in series with *m* at *B*, it not only gets the benefit of this charging current between the two sections of *m*, but it also creates a difference of potential and, therefore, disturbing currents in telephones at *A* and *C* as well.

(8) Although a proper system of transposition will prevent the establishment of an induced e.m.f. *between* the two telephone wires, it does not necessarily prevent the two wires from assuming a potential which differs from that of the earth. In a properly transposed system, each telephone wire is the same average distance from each power wire. The potential, therefore, which the telephone system tends to assume from the static induction of the power wires is that of the neutral point of the power system. By neutral point is meant that point between which and each of the power wires the average e.m.f. is the same. Under normal conditions this neutral point is at ground potential. If, however, leakage takes place from one of the power conductors to ground, this neutral point will differ in potential from the ground and the amount of this difference becomes greater as the resistance of the leak becomes less. In a three-phase system, when the resistance of this leak becomes zero, the maximum difference of potential between the neutral point and ground occurs, and is 58 per cent. of the power circuit voltage. In a 20,000 volt system, for instance, there may exist a potiential of nearly 12 000 volts between the neutral point and ground. When the neutral point of the power line differs in potential from the ground, an electrostatic difference of potential tends to exist between the telephone wires and earth, and will exist if the insulation of the telephone circuit is perfect.

(9) The amount of this electrostatic potential between the telephone circuit and the earth will depend upon the relative capacities between power and telephone lines on one hand and between telephone line and earth on the other. The power and telephone lines may be considered as opposite plates of one condenser and the telephone line and ground as opposite plates of another condenser. These two condensers being in series, they will distribute the total e.m.f. in inverse ratio to their capacities. With usual construction, the capacity between telephone line and ground will not be less than that between telephone and power wires, so that the potential of the telephone wires above ground

will be equal to at least one-half the potential of the power line neutral point above ground. A grounded power line may thus cause a potential between the telephone wires and ground which will reach well into thousands of volts and even a bad insulator may cause such an e.m.f. measured by hunderds of volts. In this connection it is significant to note that in the great majority of cases the telephones become inoperative when a ground occurs on the power lines. Is it any wonder? How many telephone lines are built to stand up under a strain of even 1,000 volts, let alone 5,000 or 10,000 volts to ground? It is hardly necessary to point out the path of the disturbing currents. The first voltage strain comes not between telephone wires, but between the two wires and ground. A break down of its insulation, either partial or complete, occurs at some point, and the wire to which the break occurs discharges to ground either partially or completely and the other wire must discharge *through the telephones* to ground.

(10) The points, therefore, which deserve careful consideration in the installation and operation of a telephone line when it is to be operated in proximity to a high-tension transmission line are the following:

(1) Insulation.
(2) Transpositions.
(3) Use of bridge telephones instead of series telephones.
(4) Making static capacity of telephone wires to ground as great as possible, and capacity to power wires as small as possible.

(1) *Insulation.*

(11) Insulation is put first as being the point of first importance. A ground on the transmission line is going to cause either volts or trouble on the telephone line. There is no reason why the telephone wires will not transmit speech properly, even if it does differ in potential from the ground. But to obtain this result, disturbing currents from the line to earth must be prevented by perfect insulation. When it is realized that the potential between the telephone line and ground may be as high as 30 per cent. of the potential between power wires, the importance of insulation is better understood. By insulation, too, is meant the insulation throughout the entire line. There is little use in providing glass insulators for pole supports capable of standing a voltage of 15,000 or 20,000 and then, inside buildings, attaching the telephone wires directly to woodwork which may be damp, or

to an instrument mounted on a damp brick wall. Above all, there is no use in putting up a line which may be able to stand a test of 15,000 or 20,000 volts, and then attach to this same line a lightning arrester which will break down at 300 volts, as the standard telephone lightning arrester is expected to do.

(12) When providing high tension insulation for the telephone line, the insulation of the man using it should not be forgotten. This insulation of the telephone user is advisable, not only to protect him from the induced voltage but also to protect him in case of a cross with the power line. The induced voltage is not so dangerous as its amount would indicate because the current is limited to that of a condenser consisting of power line as one plate and the telephone line as the other. It may be noted that the telephone insulation is subjected to high strains only when the power line is grounded or heavily unbalanced statically. This is just the time, however, that uninterrupted service of the telephone line is apt to be of the utmost importance.

(2) *Transpositions.*

(13) The necessity of transposing the telephone line is almost so apparent as not to need comment. Otherwise continuous disturbances will exist, due both to electromagnetic and electrostatic effects. So far as the telephone line is concerned, transposition of the power wires is not so important. An untransposed power line cannot induce either electrostatic or electromagnetic effects between two transposed telephone wires, but only between these two wires and ground. The amount the statically balanced untransposed power line can elevate the telephone wires above the ground potential is small compared to the effect of the power line when statically unbalanced, whether transposed or untransposed. If the telephone line is insulated to meet the worst conditions, it will be ample to meet the normal condition of an untransposed power line.

(3) *Use of Bridge Instead of Series Telephones.*

(14) This point is one which need only be mentioned. The advantages of the bridged over the series telephone are so well known that the reason before mentioned for using a bridged instead of a series instrument is simply throwing another shovelful of earth on the grave of the series instrument.

(4) *Making Capacity of Telephone Wires to Earth as Great as Possible, and Telephone Wires to Power Wires as Small as Possible.*

(15) In Montana there is a line in operation at 50,000 volts.

Other lines are projected as high as 60,000 to 80,000 volts, and there is a possibility of going higher. When one realizes that with the usual construction as shown in Fig. 1, there may be in such cases an elevation in the potential of the telephone wires of 20,000 to 25,000 volts above ground he begins to cast about for some method of reducing this potential. The total voltage between the neutral point of the power wires and ground may be considered as taken up across two condensers, one consisting of the power and telephone wires, and the other the telephone wires and earth. To decrease the possible potential of the telephone wires to ground, therefore, one must either decrease the capacity of the power wire—telephone wire condenser, or increase the capacity of the telephone wire—earth condenser, or both. This may be accomplished by increasing the distance between power and telephone wires, and decreasing the distance between telephone wires and earth. If the same supporting structure be used, there is a limit to which this can be carried, at which the possible voltage between telephone wires and earth may be still prohibitive. The capacity of the telephone wire-earth condenser, may be still further increased by bringing the earth to the telephone wires, instead of the telephone wires to earth. That is, one or more ground wires may be run in close proximity to the telephone wires, thereby increasing the capacity of the telephone wire-earth condenser, to almost any desired limit. By this means the possible potential between telephone wires and earth may be brought within limits where it may be taken care of with safety.

(16) In conclusion, the writer asks for the freest comments on the foregoing remarks, particularly from those who have had experience in operating a telephone line paralleling high-tension wires. If such can agree with the writer in his remarks, he will be pleased to know it. If they cannot agree, he will be still more pleased to find out wherein he is wrong.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27th, 1903.

BURNING OF WOODEN PINS ON HIGH-TENSION TRANSMISSION LINES.

BY C. C. CHESNEY.

Facts concerning a number of examples of the burning of wooden insulators pins and a recommendation as to the use of iron pins.

In this country it has been almost the uniform practice in high-tension pole line construction to use wooden pins. The reason for their use has been the belief that because they were made of wood they strengthened the entire insulation of the pole line system, and were in consequence additional safeguards. These pins have generally been made of locust, oak or eucaliptus; and in order that the insulation might not deteriorate from the action of the weather, they have usually been treated carefully with hot asphaltum, paraffine or linseed oil. The temperature and character of the treating liquid have depended more or less upon the whim of the constructing or designing engineer. Although there has been no uniform method followed and although the materials used in the treatment have differed greatly, the results have been universally the same. Wood pins when used with glass or well vitrified porcelain insulators, have given very good service on potentials as high as 25,000 or 30,000 volts. There have been no unusual pin troubles at these voltages which could not readily be explained by porous or cracked insulators or by some peculiar climatic conditions. In my opinion, the success secured in the operation of the great majority of these lines is due to good insulation of the insulator, and the insulation of the pin has in reality contributed very little to that success. For 40,000 volts and for higher potentials, the insulators offered by all manufacturers do not have the same factors of safety as

the insulators for lower voltages offered by the same manufacturers. The difference is not so much in the thickness or in the quality of the glass or porcelain used; it is more particularly in the general shape of the insulator and in the dimensions of the insulating surfaces and petticoats. For this reason, even under severe local surroundings, the 10,000, 15,000, 20,000 or 30,000 volt insulators have shown very little surface leakage and in consequence there has been comparatively little pin burning at these voltages. It is true that in localities of salt storms, of

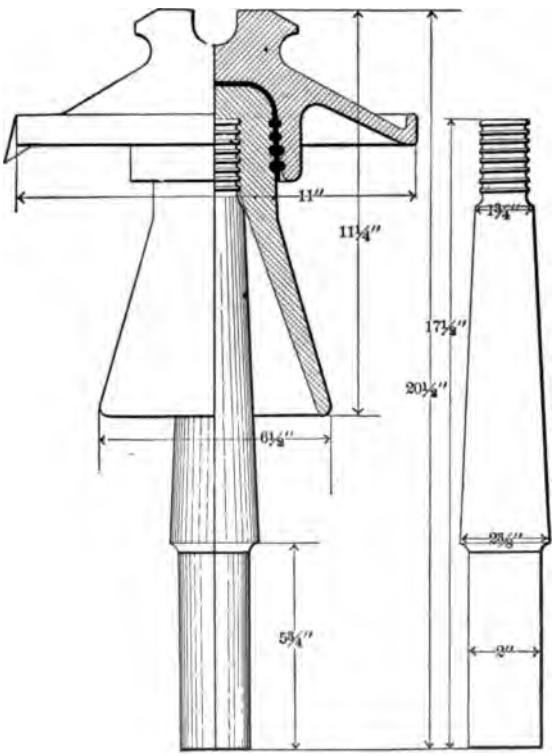


FIG. 1.

heavy sea fogs or chemical factories, there has been more or less pin burning without regard to the type of insulator used, or to the potential of the system. The writer has been informed that a certain plant using only 440 volts has at times great trouble from the burning of pins, although 10,000 volt insulators are used. This trouble is due entirely to the deposit on the insulators from a neighboring chemical factory, and as might be expected their period of no-burning is during the rainy season. These instances

however, are rare, and when the cause is apparent, the remedy is usually at hand. The pin burning on 40,000 and 50,000 volt lines is somewhat different. Eliminating all causes due to broken or defective insulators, the actual flow of current over the surfaces and through the body of the pin is probably very small. On the lines from which the writer has secured burned pins two used 11-inch Locke insulators, as shown in Figs. 1 and 2; the third used the Redlands type, Fig. 3. The first two lines were operated at a potential between 45,000 and 50,000 volts, and the

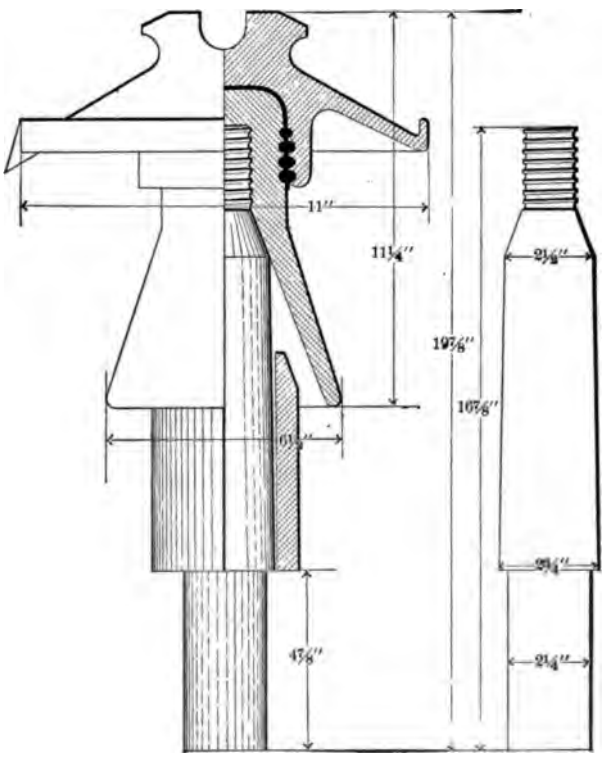


FIG. 2.

third at about 33,000 volts. The pins shown were taken from perfect insulators and in some cases the insulators were immediately put back on the line. Pins shown in Figs. 1 and 2 were made of eucaliptus and boiled in linseed oil. The line using pin shown in Fig. 2 also used a porcelain sleeve covering the base of the pin. Fig. 3 shows the well-known Locke iron-pin with porcelain base and oak thread. Fig. 4 and Fig. 5 show three pins all of the type shown in Fig. 1. These pins were taken from the same

pole and occupied the relative positions as shown in the cuts. The burned sides stood towards the damp winds from the ocean. Fig. 6 shows a burned pin of the type shown in Fig. 2. Fig. 7 is the Locke iron-pin with porcelain base (Fig. 3) taken from a 33,000 volt line. The striking feature is the burning of the wooden thread to the iron pin. The writer has been informed by the general superintendent of this plant that every pin that has been examined on this line is burned in exactly the same way, yet

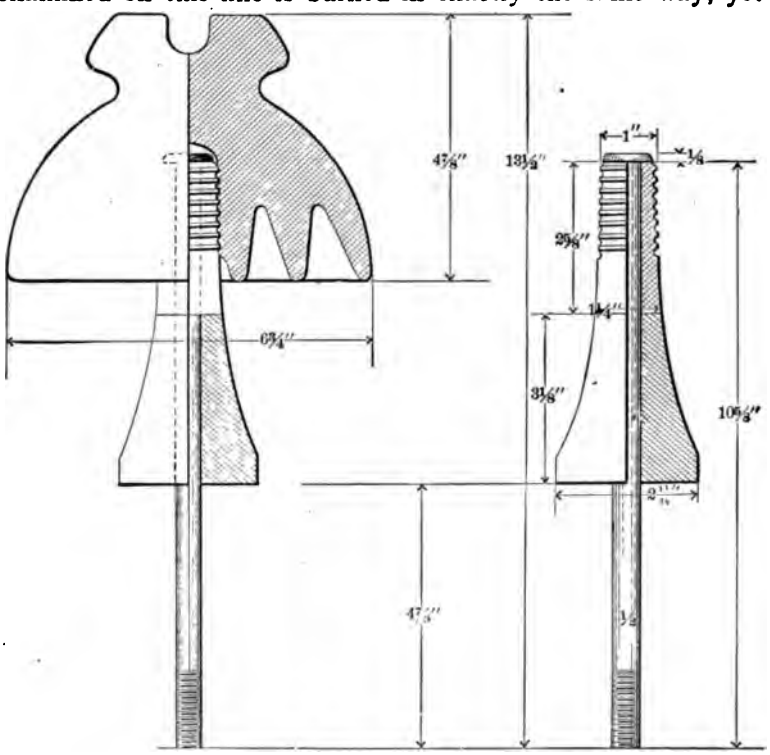


FIG. 3.

there has been comparatively few punctured insulators and no cross-arms burned from the current leaking over the surface of the insulators. Fig. 8 shows the pin taken from the same 50,000 volt line as those shown in Fig. 4. This pin is shown sawed in sections in Fig. 9. The noticeable feature is that the burned section is entirely in the upper part of the pin about 1¾" below the thread. The outside surface and the centre of the pin below this point shows no charring. It would appear that at least in this instance the burned section was the point of highest resistance of the pin, and that the lower part of the pin was a good

FIG. 5.

FIG. 4

Fig 8

Fig 7

Fig 6

Fig 10.

Fig 9.

enough conductor to permit the small current which leaked over the surface of the insulator to flow without any special generation of heat in that section of the pin. The reduced insulation of the pin and insulator was no doubt due to the dust and fog. The upper portion of the pin, being better protected by the insulator from fog and dust, had in consequence higher surface resistance. The dark spot shown on the right hand edges of the lower section of Fig. 9 is the sap section of the wood and has been discolored by the linseed oil boiling which the pin originally had. This section has been in no way affected by the current. In Fig. 9 is illustrated a peculiar action which is occasionally found on high tension transmission lines, and which, for a better name, has been called " digesting the thread of the pin." The thread of the pin softens while in service and may be rubbed off with the fingers. This soft wood has a sour taste and resembles digested wood pulp. This action is not necessarily accompanied by the burning of any portion of the pin.

The evidence here presented, while not conclusive, still points to the advisability of using iron pins with modern insulators properly chosen for the line potential.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27th, 1903.

MODEL SHOWING DISTRIBUTION OF ELECTROMOTIVE FORCE AND CURRENT ALONG A SINGLE PHASE ALTERNATING CURRENT TRANSMISSION LINE.

BY W. S. FRANKLIN.

A helical line drawn on the surface of a transparent cylinder and set rotating about its axis would appear to an observer looking at it from one side as a wave-line traveling along the axis. The direction of travel of this wave-line would be one way or the other, according as the helix is right or left-handed.

A rotating right-handed helix would represent the electromotive force waves (or the current waves) traveling outwards from a generating station along a transmission line having inductance and capacity, but having neither resistance nor leakage.

A left-handed helix rotating in the same direction about the same axis would represent the electromotive force waves (or the current waves) reflected back from the receiver. A compound helix of which the radius-vector at each point along the axis is the sum of the radii vectores of the two simple helices would, if set rotating, represent the actual distribution of electromotive force (or current) along the transmission line.

The effect of line resistance and line leakage is to cause the waves of electromotive force and current to diminish in amplitude as they travel along the line.

Imagine a helix-like line drawn about an axis, the radius-vector of this helix-like line at a point along the axis being proportional to ε^{-x} where ε is the Naperian base and x is distance measured along the axis from one end. If this helix-like line is set rotating about the axis, it will appear to an observer looking at it

from one side as a wave-line traveling along the axis and diminishing in amplitude as it travels along.

A rotating, right-handed helix-like line of the kind just specified would represent the electromotive force waves (or the current waves) traveling outwards from a generating station along a transmission line having inductance, capacity, resistance and leakage.

A left-handed helix-like line rotating in the same direction about the same axis would represent the electromotive force waves (or the current waves) which are reflected back from the receiver.

A compound helix-like line of which the radius-vector at each point along the axis is the vector sum of the radii vectores of the two single helix-like lines, would, if set rotating, represent the actual distribution of electromotive force (or current) along the transmission line.

The model which is herewith exhibited contains: (A), Two simple and one compound helix-like lines, which represent outgoing, reflected, and resultant electromotive force waves respectively; and (B), Two simple and one compound helix-like lines which represent outgoing, reflected, and resultant current waves respectively.

This model was calculated and constructed by Messrs. J. H. Flory and C. W. Startsman, as a graduating thesis in electrical engineering, at Lehigh University in 1901.

The calculations were based upon the following data:

Length of line, 200 miles.

Resistance of line one ohm per mile.

Reactance of line due to inductance four ohms per mile.

Leakage conductance of line, 0.00002 mho's per mile.

Capacity susceptance of line, 0.0002 mho's per mile.

Receiver is a condenser having a reactance value of 100 ohms.

The actual value of electromotive force (or current) is not essential to the interpretation of the model but as a matter of fact the voltage at the terminals of the receiving circuit was taken to be 10,000 volts and the current, of course, 100 amperes.

Discussion.

President Scott:—The subject of the meeting this evening is Power Transmission on High-Tension Lines.

There are a number of different subjects to be presented; these have been prepared by the members of the Transmission Committee as introductions to discussions, not as complete, formal and exhaustive papers in themselves, but written with the intent of calling attention to and introducing a number of points on the several subjects which would lead to contributions from others. Mr. Mershon and I think that the best method of conducting the meeting this evening would be to take up each subject in turn and to devote a specified time to it, so that some attention could be given to all. The gentlemen having the subjects in charge will have a certain amount of time at their disposal. They can present the written material first and then the subject will be open to general discussion for the remainder of the half hour which will be allotted to each of the subjects. The first topic is "Mechanical Specifications for a Proposed Standard Insulator Pin," by Ralph D. Mershon.

Mr. Ralph D. Mershon:—Before the discussion is begun, I wish to state that my object in writing this introduction was to get a discussion sufficiently full to form the basis of recommendation to the Standardization Committee.

There are a number of written contributions which I shall read. The first is from Mr. M. H. Gerry, Jr., of the Missouri River Power Co.

Mr. M. H. Gerry, Jr.—It is too early in the development of high-tension transmission to attempt to make standard the details of construction. Such action at this time by the Institute would

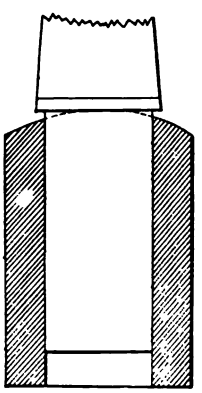


FIG. 1

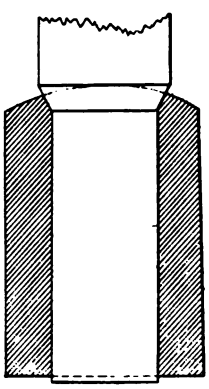


FIG. 2

result not only in failure, but in a tendency to prevent advancement in this line. However, a full discussion by the membership cannot fail to be of great advantage and profit.

Mr. Mershon has suggested the adoption as standard of certain forms of wooden pins, the designs of which conform to common

construction. Most engineers of experience, however, would be in favor of a diameter greater than one inch at the top of the pin, and a greater length of thread than two and one-half inches. Wooden threads most frequently fail by shearing, and the strength in this particular is greatly increased by a larger diameter of pin, and a greater length of thread. The longer thread is

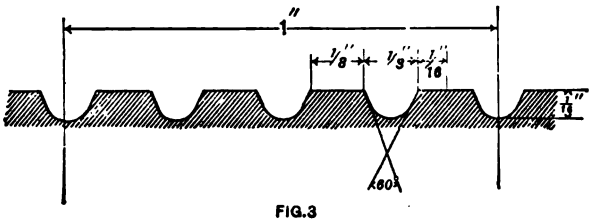


FIG.3

an advantage also in preventing the insulator from tipping out of line, when the fitting is loose between the thread of the pin and that of the insulator.

The shoulder of the pin, as suggested by Mr. Mershon, has certain disadvantages for heavy construction. On account of the rounding off of the top of the cross-arm, this form of shoulder

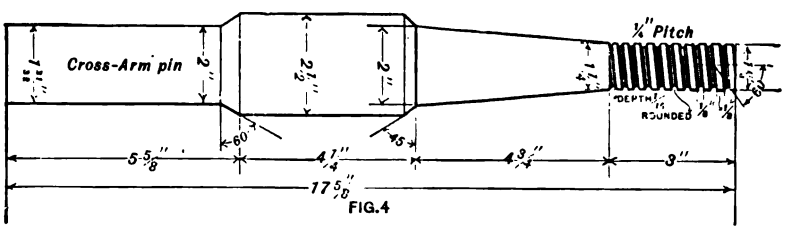


FIG.4

does not bear well, as shown in sketch, Fig. No. 1, and the sharp corner at the point of greatest strain, introduces an element of weakness. In Fig. No. 2, a form of shoulder is shown which has been used by the writer with considerable success. This shoulder tapers at an angle of 60°, and fits into a counter-bore in the top of the cross-arm. With this design the pins may be driven to a

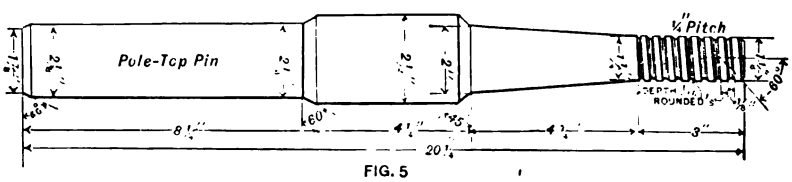


FIG. 5

firm bearing at the top of the cross-arm, which has the effect of steadying them and increasing the strength of the construction at this point.

In lieu of the form of thread proposed by Mr Mershon, the writer suggests that shown by sketch, Fig. No 3 In this design

the square top of the thread is as wide as the groove, resulting in increased area of wood to withstand shearing strains. The threads of the insulators are always stronger than those of the pins, and for this reason the form of thread as proposed has considerable advantage. This form of thread may also be easily cut, in either seasoned or unseasoned wood, and the depth not being so great the pin is stronger at the bottom of the thread.

FIG. 6

Figs. No. 4 and No. 5 are drawings of the high-tension pins now used by the Missouri River Power Company. They show the form of the thread and of the shoulder as described above, and also give the general dimensions of the pins. The upper shoulder as shown by the drawings is for the support of a glass sleeve, which is used to protect the pin from the weather. Fig. No. 6 is from a photograph of the 50,000 volt line insulator assembled on one of the pins.

MR. MERSHON:—The next written contribution is by Mr. Wlliam R. C. Corson, Electrical Engineer, of Hartford, Conn.

MR. WILLIAM R. C. CORSON:—I believe I am only concurring with the general feeling in expressing my pleasure that our Committee on High-Tension Transmission has seen fit to commence its work by an effort to standardize an essential element of construction, and in hoping that this line of effort may be continued and result in recognized and approved standards for all other items capable of a general determination.

Mr. Mershon's method of developing the table of dimensions of the proposed pin is so rational that criticism of it is difficult. Briefly stated, of course, this method assumes the pin in general use as a basis, and mathematically determines the diameters of pins of differing length, which shall be capable of sustaining the same tension at their extremity as will this pin. In other words, the safe load that may be applied at the top of the proposed pins is of constant value in all. This value is not discussed in the "Introduction," and feeling that its determination would be of interest to me, and might prove of value, I have made a series of tests in a Sellers' machine to ascertain the value of s in equation (1,) for the ordinary locust pins, under the actual conditions of support suggested.

Six standard locust wood pins were selected at random from a supply at hand. The larger diameter of the shank varied from 1 7/16 inches to 1½ inches, while the smaller diameter was uniformly 1 11/32 inches. These were supported in a 1½ inch hole in a hard wood block, and the measured tension applied about 4½ inches from the block, the exact distance of the point of application being measured.

The load was very gradually applied in increments of a few pounds, and the amount noted when the first separation of the fibre appeared. Most of the specimens showed distress at from 700 to 750 lbs., with maximum strength of about 10 per cent. above this. One specimen, however, showed a crack at 600 lbs., and an ultimate strength of 1083 lbs. The average value of s determined from the tension at which the first fibre separation appeared was 11,130 lbs. per sq. inch, and the average value calculated from the maximum loads sustained was 13,623. The value of s, calculated for the specimen crackling at 600 lbs., was 9,280. While this is somewhat below the average due to an apparent defect in the wood, it is probably best to assume that for a maximum load, s should not be greater than 9,000. Assuming this value, the maximum load that may be applied to the proposed pins at a distance from the cross-arm equal to the designation of size, would be as follows:

Size of Pin.	Value of P.	Size of Pin.	Value of P.
5 in.	557	13 in.	621
7 "	639	15 "	694
9 "	615	17 "	670
11 "	610	19 "	700

Of course these values of P would be identical but for the difference between the actual diameter selected and that of the theoretical pin. The average value is 636 lbs., which may be considered the maximum load that the standard pins will sustain at the point designated.

Even with very generous factors of safety, it would appear that the pins suggested would prove of ample strength to withstand the side strains to which they may be subjected. For heavy work and for end poles, an insulator carrying the wire at some distance below the top of the pin would, of course, increase the strength of the construction. A table of standard insulators could perhaps with advantage be prepared so proportioned between groove and bottom of threaded bore as to maintain the stress on the pin within the allowable safe values for the various tensions applied.

I would call attention to one seeming error in the table of the dimensions of the proposed pins. In the paragraph headed " Designation," the following appears: " It is proposed to designate that portion of the pin above the cross-arm as the ' stem ' of the pin," and further, " It is proposed to designate a pin by the length of its stem." From this definition the stem of the pin would have a length equal to the sum of the dimensions A and G of the table.. For the five-inch pin shown in the table this would be $5\frac{1}{4}$ inches, and thus is not equal to the designation.

MR. MERSHON:—Another written contribution to this discussion is by Mr. C. L. Cory, of San Francisco.

MR. C. L. CORY:—The mechanical strength of insulator pins for use on long distance transmission lines has been given much consideration by electrical engineers in California during the past six years. For the most part the insulator pins in use are wood. On the 33,000 volt, 83 mile, double circuit, three-phase transmission line of the Edison Electric Co., from their Santa Ana power house to the city of Los Angeles, iron pins with porcelain sleeves are used. This transmission is the most notable system in California at the present time using insulator pins other than wood.

Eucalyptus has been found to be perhaps the best wood to use for insulator pins. After being turned up and threaded, they are usually treated with hot linseed oil. This treatment is desirable more on account of the protection which such treatment gives the pin against weather than on account of the insulating qualities of the oil or oil treatment.

It should be understood in this connection that an insulator pin should be depended upon only to support the insulator. The insulator in turn should be depended upon to provide the necessary insulation for the line wires. No pin after being in use for a few years on a pole line can maintain to any marked degree the insulating qualities originally existing, due to such oil or paraffin treatment.

The tests outlined below were made in the electrical laboratory of the University of California, for the purpose of determining

how near the pins generally in use in California conform to the proposed standard pins suggested by Mr. Mershon. In the test twenty-two pins were broken. These were not selected particularly for the test, but were taken at random from a large lot of such pins which were to be used in construction work. Of these, twelve were of the size generally in use on transmission lines where the voltage does not exceed 30,000 volts. These pins are $11\frac{1}{2}$ inches long, including shank and stem, the latter being $6\frac{7}{8}$ inches in length. The other ten pins tested were of the size used on the lines of what has been known as the Bay Counties Power Co., now the California Gas & Electric Corporation, and the Standard Electric Co. The line voltage in each of these transmission systems is from 40,000 to 60,000 volts. These pins are

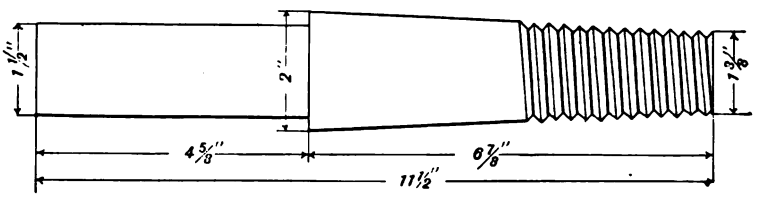


FIG. 1

$15\frac{3}{4}$ inches long, including shank and stem, the latter being $10\frac{1}{8}$ inches long. All of the dimensions of the pins tested are given in Figs. 1 and 2.

These pins do not exactly conform in size or length of stem with any of the proposed standard pins. Below, however, is given the comparative dimensions of the two samples of pins tested and the nearest sizes of the corresponding proposed pins. For sake of comparison, a 7-inch pin, as proposed, is contrasted with the $6\frac{7}{8}$ inch tested pin, and the 11 inch proposed pin is contrasted with the $10\frac{1}{8}$ inch tested pin. The above dimensions refer to the length of the stem of the pin, as suggested by. Mr Mershon.

COMPARISON OF PROPOSED PIN AND PINS TESTED.

	Size of Pin.	A	B	C Nominal	C Actual	D	E	F	G	H	I
Proposed Pin.	7"	7"	$4\frac{1}{4}$"	$1\frac{1}{4}$	$1\frac{3}{32}$	$1\frac{11}{16}$	$1\frac{1}{4}$	1"	$\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{2}$
Pin Tested.	$6\frac{7}{8}$	$6\frac{7}{8}$	$4\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{4}$	—	2"	3
Proposed Pin.	11	11	$4\frac{1}{4}$	2	$1\frac{31}{32}$	$1\frac{13}{16}$	$1\frac{1}{4}$	1"	$\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{2}$
Pin Tested	$10\frac{1}{8}$	$10\frac{1}{8}$	$5\frac{3}{8}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$2\frac{1}{8}$	$1\frac{1}{4}$	$\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{2}$

In general, it will be seen that the dimensions of the proposed and tested pin agree fairly well. The most marked difference is in the diameter of the portion of the pin which is threaded to

receive the insulator. It seems evident that one inch is not a sufficient diameter for the thread of the pin for all sizes. If there is any burning of the pin just below the insulator, the inevitable result will be breaking at the bottom portion of the thread. Such a break will usually leave the pin, except the threaded portion, standing in the cross-arm, while the insulator with the threaded portion of the pin inside, will hang suspended on the line wire. This sort of break has often been observed on high-voltage transmission lines.

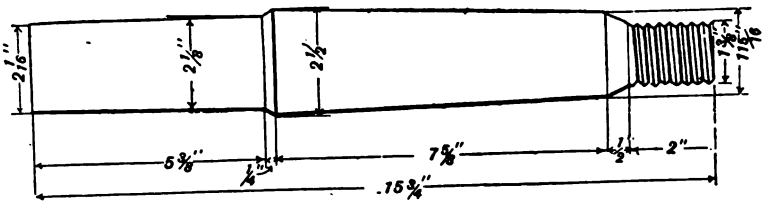


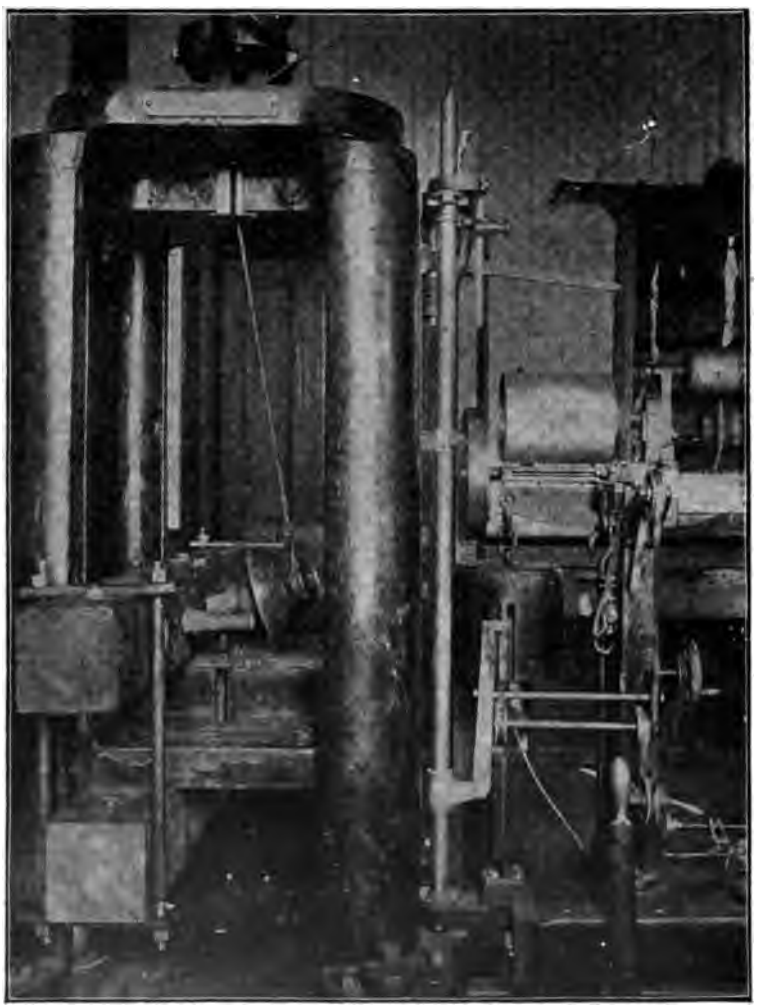
FIG.2

The method of testing the pins is clearly shown in the accompanying photograph. It was impossible to mount the cross-arm in the testing machine so that the strain on the pin would be at right angles to its axis. The variation from a right angle, however, is small and to a certain degree conforms with the direction of the strain on the pin, due to the sag in the line wire. The " breaking load," as given in the tables below, refers to the strain in the direction of the cable, while the " real breaking load " is the component of this strain at right angles to the axis of the pin.

No.	Breaking Load.	Real Breaking Load.	No.	Breaking Load.	Real Breaking Load.
1	1010	950	1	2250	2120
2	1090	1035	2	3140	2960
3	1450	1360	3	2380	2240
4	1360	1280	4	2010	1890
5	920	865	6	2780	2620
6	1220	1150	7	2280	2140
7	1350	1270	8	1570	1475
8	940	875	9	2390	2250
9	1360	1280	10	3390	3190
10	1360	1280	Average.	2465	2310
11	750	705			
12	1060	1010			
Average.	1155	1085			

The average results, referring to the " real breaking load," of the tests of the two pins are respectively, 1085 pounds for the 6⅞ inch pin and 2310 pounds for the 10½ inch pin. The character

of break in the two pins, however, is not the same. Almost without exception, the 6⅞ inch pins were broken approximately square off at the cross-arm. The larger pins, however, split in the stem, the beginning of the split being just at the bottom of the thread. An inspection of the photographs clearly shows the difference in the character of break in the two pins.



Method of Mounting Cross-Arms, Pins and Insulators in Testing Machine.

It seems from the tests that the shank is the weakest part in the 6⅞ inch pins, while the stem, and particularly the upper portion of the stem, or thread, is the weakest part of the 10⅛ inch pins

The variation of the " real breaking load " for the different 6½ inch pins tested is from 705 pounds minimum to 1360 pounds maximum. For the 10½ inch pins, this variation is from 1475 pounds minimum to 3190 pounds maximum.

During the progress of the test, it was observed that the " allowable breaking load " was least when the pin was turned in the cross-arm, so that the strain was across the grain of the pin, while the greatest allowable "breaking load" corresponded with the position of the pin in the cross-arm, so that the strain was parallel to the grain of the pin. In the tests made, no particular care was taken to turn the pins in any fixed position relative to the grain of the pin and the direction of the strain applied.

For good construction on lines using 30,000 to 60,000 volts the larger pin must be used. It does not seem, however, that any good reason exists for a great number of different sizes of pins, as it would seem probable that the two sizes tested might be used to fulfil almost every requirement for transmission work where wooden pins are at all allowable.

In many respects an iron pin is better than one of wood. In the first place, to secure sufficient strength in the shank, the wooden pin must be of such a large diameter that the size of the cross-arm is necessarily increased. In addition, using an iron pin, the insulator can be held down on poles or supports where the tendency of the line wire is to raise or pull the pin out of the cross-arm. In using wooden pins, this is usually prevented by driving a nail through the cross-arm into the shank of the pin.

An iron insulator pin, possessing many desirable features, has been designed for use on the extensive transmission lines of the Vancouver Power Co., of Vancouver, British Columbia, the design being due to Mr. Wynn Meredith, of San Francisco. In general, the pin consists of a steel bolt approximately 12 inches long. A cast iron sleeve 4½ inches long, and fitting closely to the cross-arm, fills the space between the thread, and corresponds to the stem of the ordinary wooden pin. The thread of the pin is made of lead, this lead thread being cast upon the end of the steel bolt, the steel bolt being first chopped or made ragged, so that the lead is held firmly to the steel bolt after being cast.

The tests upon this form of pin have not as yet been completed, but as soon as possible the results will be presented to the INSTITUTE.

MR. MERSHON:—The fourth and last written contribution to this part of the subject is by Mr. D. L. Huntington, electrical engineer of the Washington Power Company, Spokane, Wash.

MR. D. L. HUNTINGTON:—Wooden pins are subject to so many uncertainties when used in connection with very high voltages, especially where the atmosphere contains salt, smoke or dust, that it seems desirable to abandon their use for such purposes wherever possible, and to substitute a metallic pin. The construction of a long distance line for 60,000 volts, led the writer to make some investigation as to what could be done in this direction, without excessive cost.

It was decided that a drop-forged or a turned steel pin would be so expensive as to exclude it, even if the time at our disposal would have permitted us to wait for its delivery.

Experiments were made with a cast-iron pin almost identical in dimensions to that shown in Fig. 2 of Mr. Chesney's paper, except that it was cored out internally so as to make its weight about 10 pounds. The diameter of the shank was $2\frac{1}{8}$ inches. This pin, before fracturing, sustained a load slightly in excess of 3,000 pounds, suspended from near the end of the threaded portion.

Fear was felt, however, as to what might occur under the sudden strain of a line parting in winter time, with the possibility

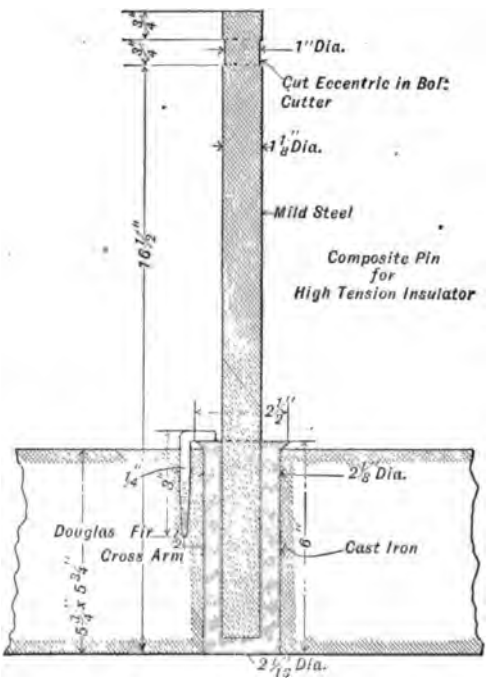


Fig. 1.

of the fracture of several pins at a time due to the sudden shock.

To avoid this, several designs were made of pins cut from round steel bars of 1 inch and $1\frac{1}{8}$ inch diameter. The difficulty in obtaining a satisfactory shoulder for the pin at the cross-arm proved serious. Furthermore, it was feared that with a pin of that small diameter, the cross-arm would be likely to burn out at the pin-hole, as the interior surface of the hole would be comparatively small for distributing the leakage currents to the cross-arm. Moreover, actual experience with wooden pins has shown more or less conclusively that with a shank diameter of

two inches or greater, there is little or nothing to fear from this trouble.

As a result of these several difficulties we have designed and adopted a pin (see Fig. 1) eighteen inches long, made of 1⅛ inch round mild steel bar, and having a shoulder and shank cast upon it as shown. This pin we find will begin to bend when loaded with about 1,000 pounds at the upper end, the shank being rigidly supported. This is much lower than the results obtained by the cast iron pin referred to above, but it is believed that it is more reliable and that it is sufficient for nearly all ordinary work. In addition, the steel bar will not snap off under sudden shock, but will support the insulator and line safely even when badly bent. We were unable, in the time at our disposal, to investigate what could be done in the way of malleable castings of a design somewhat similar to the cast-iron pin mentioned above, but it is the writer's opinion that it would prove a fruitful line of investigation.

High freight rates of the west and a higher initial cost will doubtless make some of those in charge of the construction of such lines hesitate at the extra expenditure (in our case it was about double the cost of eucalyptus pins), but it is in the line of safe and conservative engineering and certainly strengthens the weakest link in our high-voltage chain, our lines.

MR. W. N. SMITH:—It seems to me that the dimensions given are all very well for a pin carrying a certain weight of wire, but it does not seem to me that a single standard table of dimensions could be laid down to cover anything like all the conditions of various power transmission lines, all the way from a line of 5,000 or 6,000 volts, with, say, No. 4 wire, up to one like the Niagara Falls power transmission line, which is of 300,000 c.m. cable. The scheme of the tabulation should be enlarged and gone over carefully, so as to have a separate tabulation for a reasonably small range of weights of copper wire to cable; that is, one table for sizes from No. 6 to No. 3, another No. 3 to No. 0, another from No. 0 to No. 0000, and another from No. 0000 up. In this way the design of a standard pin would more nearly meet the varying conditions of transmission line construction. I remember reading Mr. Stillwell's paper a year or more ago on the Niagara Falls transmission plant, in which, if I remember correctly, he stated that the principal trouble with pins was their breaking at the root of the thread. I do not see that this point has been covered in Mr. Mershon's discussion, although it was referred to in Mr. Gerry's contribution. I should think it a matter of considerable importance in the design of the pin. I further agree with Mr. Gerry in his opinion that the top of the pin is rather small, certainly, for the very heavy insulators that would be required for a transmission above 30,000 volts.

MR. P. H. THOMAS,:—It would be a great gain to those who hope to get information from the report of the committee, if the characteristics of the different types of wood commonly used

could be discussed, *e.g.*, oak, eucalyptus and locust. It is to be hoped that in the local sections this question will be very fully discussed. Also, something should be said about the method of treating pins, which is one of the most important questions in the insulation of the line. The treating of pins to make them waterproof, without injuring the mechanical strength, is a difficult matter.

In putting up an insulator, where the pin comes to a bearing on its end inside of the insulator, expansion of the pin or contraction of the insulator may crack off the top of the insulator, especially with glass. To amend this difficulty, a shoulder might be arranged so that the pin would not touch the top of the insulator.

MR. MERSHON:—As to the question of the size of the pin, it may be desirable to have a pin larger at the top, perhaps, but I do not think the reason which has been given for this holds very well. In the first place, an insulator properly designed will not tip. If the insulator is designed so that the side pull of the line on it is transmitted directly to the pin, instead of being all the way from an inch and a half to two inches above the top of the pin, as in the case of most insulators, it will not tip. If it does, that is a fault in the design of the insulator and not in the dimensions of the pin. Mr. Gerry has criticized the shearing strength of the thread. I doubt if the thread of the pin proposed by Mr. Gerry will have a greater shearing strength than the thread of the pin referred to in the paper. The question of the shearing strength is not so important. A well-designed line will not have much up-strain. A line with much up-strain is not laid out as it should be. You cannot prevent some up-strain on some insulators, but it may be made so light that the shearing strength of the thread will not be of much importance.

VICE-PRESIDENT SHELDON:—If there is no further discussion, we will proceed to the next paper. Do you care to make any closing remarks, Mr. Mershon?

MR. MERSHON:—There was a further remark made by Mr. Gerry to the effect that it is too early to adopt a standard pin. I think if we adopted a standard and changed it from year to year, we should not be any worse off than we are now, when we have no standard. There are as many standards as there are manufacturers of pins and designers of pole lines. The only way now to get a pin to fit an insulator is to send the insulator to the pin manufacturer and in that way have the pins made so that they will fit. If you buy a pin from one manufacturer and the insulator from another, they may fit, or they may not fit.

VICE-PRESIDENT SHELDON:—We will now proceed to the discussion of the paper by Mr. F. O. Blackwell on "The Testing of Insulators." As Mr. Blackwell is not present and has not delegated any one to present his paper, I will call upon Mr. Mershon to present the introduction.

MR. MERSHON:—If there is no objection, I will pursue the same course in regard to Mr. Blackwell's introduction as with

my own. I will omit reading his introduction and read the contributions to it. I think they take up most of the main points and will serve as a basis for the discussion this evening. The first contribution is by Mr. M. H. Gerry, Jr. It is as follows:

MR. M. H. GERRY, JR.—Mr. Blackwell has ably discussed a number of important matters in connection with the testing of high-voltage insulators. There are, however, a number of additional points which have not been touched upon.

Insulators are tested for two purposes: first, to determine the design, shape, material and dimensions best suited for a given voltage and set of conditions; secondly, insulators are tested as a matter of routine, to determine whether manufacturers have complied with specifications regarding material and workmanship.

There can be no complete set of tests to cover the first purpose, as it is not only a matter of experiment, but of skill and judgment in properly interpreting the results of many tests, in relation to service conditions. The testing of insulators for the second purpose is comparatively simple. For glass insulators it is usually sufficient to inspect them for physical defects, such as cracks, bubbles and incorrect dimensions. A certain percentage of the insulators should also be tested for proper annealing, and for mechanical strength. A chemical analysis of the glass of a few of the insulators is also desirable. Electrical tests of glass insulators are unnecessary, as the physical inspection will reveal everything that can be found by an electrical test. Porcelain insulators are more difficult to test than are glass insulators, on account of many defects being covered by the glaze. For very high voltages, porcelain insulators should be tested electrically, and should also be carefully inspected during the process of manufacture, and before the glaze is applied. This is especially desirable with insulators built up of several parts and cemented together by glaze or other material. Defects in insulators of this type are difficult to detect, even by electrical tests, unless they are pronounced.

Mr. Blackwell has indicated the proper method of making electrical tests of insulators. The puncture test mentioned by him, of twice the potential between wires, is usually sufficient, but a higher test is desirable where the insulators are to be exposed to severe lightning strains.

MR. MERSHON:—I would like to speak in regard to the following sentence in the contribution of Mr. Gerry, which has just been read. "The puncture test mentioned by him (Mr. Blackwell), of twice the potential between wires, is usually sufficient, but a higher test is desirable where the insulators are to be exposed to severe lightning strains." I have never personally known or heard of a case of insulators having been punctured where the puncture could be laid to lightning. It seems to me the lightning would flash around most insulators rather than puncture them.

Then as to the question of the chemical analysis of glass insulators. I have never had any reason to think that the chemical composition of the glass made any difference in the behavior of glass insulators. I have made tests for difference in behavior due to composition on both insulators and tubes of glass, but never succeeded in finding any.

VICE-PRESIDENT SHELDON:—The subject is open for general discussion.

MR. P. M. LINCOLN:—I would take issue with Mr. Gerry, who made a statement that glass insulators did not need testing beyond visual inspection. I know of a certain line, the insulators of which were not given a voltage test, but were simply tapped with a mallet in order to eliminate, if possible, any which had undue internal strains. After the insulators were up and the normal voltage applied, quite a number of them broke down in actual service, which probably would not have occurred if they had been tested with voltage before being erected.

Another point, in regard to lightning, which Mr. Mershon speaks of—it is a fact that rain usually accompanies lightning storms, and that, of course, will give you a wet surface on the insulator. This wet surface is a very good conductor of the sudden surges which occur in lightning storms, so that lightning strains will be very apt to go over the surface rather than through the insulator. I do not think there is much danger of breaking down of an insulator from lightning strains, after a test of double normal potential has been applied.

VICE-PRESIDENT SHELDON:—Is there any more discussion?

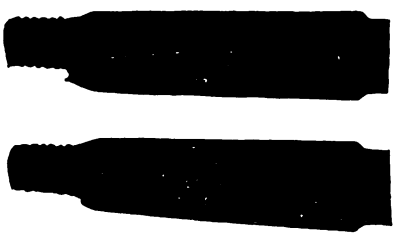
MR. W. N. SMITH:—While the subject is before the INSTITUTE, I think it would be quite interesting if any members present would state their preferences between porcelain and glass for high-tension insulators. It is a question that comes up every now and then, and no doubt there are members present who may have a very strong leaning toward one or the other material for high-tension transmission.

MR. MERSHON:—As between glass and porcelain, it seems to me about the only advantage, other things being equal, that porcelain has over glass for transmission work is that of mechanical strength. Sometimes it has that advantage and sometimes it has not. It is a fact, however, that in some forms of insulator —in some complex forms—it is possible to get the porcelain insulator cheaper than the glass one. I have found this true, to my surprise, in one or two cases. When the insulator is large, so that it takes the form of a very heavy central portion of glass, with long, thin petticoats, it seems to be almost impossible to make it of glass and have it symmetrical. The thinner portions cool first, and when the insulator is taken from the mold the weight of the outer portions distort the inner portion of the insulator, which is still hot. An advantage has also been claimed for porcelain over glass because of the lesser hygroscopic effects, but I think in most power transmissions the small amount of power necessary to dry up whatever moisture will get on the

surface of the insulator in that way would not be serious. As a matter of fact, in any measurement I have ever made, no difference could be detected between porcelain and glass in the matter of losses over their surfaces at high voltages.

MR. T. W. SHOCK:—I had the pleasure of building a line this last year in the State of Pennsylvania, in which I used an insulator which tested for 75,000 volts. The ordinary pressure will be 24,000 volts—that gives a factor of safety of over two. I think I agree with Mr. Blackwell, that in testing insulators for a line of high pressure the testing pressure should be at least two and possibly three times the ordinary line pressure. My idea in adopting that style of insulator is due to the fact that it was built for a line on the Pacific coast, for 40,000 volts, and I adopted it to give me an extra factor of safety. I made the test at a pressure of 75,000 volts. I think the insulator will give us very good satisfaction.

MR. F. N. WATERMAN:—Mr. Blackwell's reference to testing a double insulator—an insulator primarily of two parts—



Broken 10½" pins (Stem.) Total Length, 15¾" Showing How Pins Split.

requiring that each part should be separately tested, seems to me practically to bar out double insulators and does not seem to be logically founded. He says, "if it is to be tested for 100,000 volts and is made in two parts, each part might, for instance, be tested with 70,000 volts. The object of this is to have the weak parts rejected before they are assembled." The objection to that, from a practical standpoint of course, is evident; but there is a further objection, not so evident, and that is, as I understand the porcelain people, in the baking or vitrifying of the two parts it is not desirable to take the entire shrinkage out on the first heat. Consequently, if the insulators are to be tested before being filled with glaze and re-vitrified, they are not tested at all in their final condition. Furthermore, I think it is illogical for the reason that it is a well-known fact that if we get porcelain in thin parts, we have a very much more than equal chance of getting sound porcelain. That is, if the same insulators were made in one part they would only have our final test, while the double insulator with much greater initial

chance of being sound is required to be tested twice. The test peculiarly required by the double insulator is the mechanical test, and as far as my observation goes—I have tested a good many of them—if they are substantially free from large air spaces, they will stand up under the final electrical test. It seems to me that the requirement of a double test is unfair and unnecessary.

MR. THOMAS:—Mr. Gerry, Mr. Lincoln and Mr. Mershon have referred to one point in the testing of glass insulators that deserves a good deal more consideration, and that is the initial strains left in the manufacture and annealing of the glass. The breakage of glass insulators on the line during service may more often be due to too much sun on one side of a poorly annealed insulator than to electrical strain. I do not know of any test which has been suggested to determine whether glass has been properly annealed or not, but I do not doubt that some test could be gotten up, and I make the suggestion to the committee that they consider this point carefully. A successful test would save a great deal of trouble in high-tension lines after the insulators

Iron-Pin Insulator.

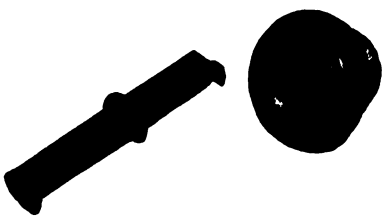
are installed. There is one rather old point which should be mentioned in the testing of porcelain insulators—not only should they be tested with salt water, but the regulator should soak a certain definite time; the Standardization Committee might determine how long.

MR. C. C. CHESNEY:—A glass insulator, if it is not properly and uniformly annealed, has unequal strains in the different parts of the glass. I have known a number of such insulators after a cool night to break when the sun struck them in the morning. The side towards the sun cracks off. Aside from this feature, I believe a glass insulator will give as good satisfaction as a porcelain one.

MR. MERSHON:—I cannot entirely agree with the author in regard to the use of one transformer for testing purposes. A series of transformers need not have a bad regulation or seriously distort the wave form, and such a testing set has a very great advantage that a transformer breakdown is much less serious than in the case of a single testing transformer. The knowledge

of this fact gives one more confidence in testing, especially in experimental testing. For very accurate results in any case a step-down voltmeter transformer is desirable.

Neither can I agree that insulators should necessarily be tested on iron pins. As I have stated before, an iron pin is likely to be the means of putting upon the insulator a mechanical stress all out of proportion to any which it would meet in practice if installed upon a wooden pin. For instance, if the insulator be screwed down tight upon a metal pin there will result stresses in the head tending to force the top of it off either at one of the threads or at the bottom of the pin-hole, or tending to burst the head. In either case there is a resulting mechanical strain in the substance of the insulator inviting puncture perpendicular to the lines of stress. An insulator that will stand up well under a salt water test, will often break down quickly when tested on a metal pin. While I do not believe in depending upon the wooden pin for insulation, I see no good reason for condemning it in general where there will be no

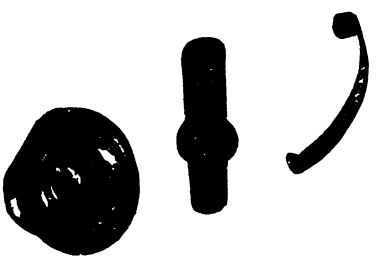


Parts of Iron-Pin Insulator.

trouble from burning. The author says that wooden pins burn off eventually unless the insulator be good enough to be used with an iron pin. If the insulator be good enough to prevent burning of the wooden pin, why not use the wooden pin unless there be some mechanical requirement which it cannot meet.

I agree thoroughly that any new type of insulator should be given a rain test; that is, a voltage test while water is being sprayed upon the insulator in imitation of rain. If a wooden pin is used in this test, it should be covered with tin-foil from a point inside the petticoat nearest the pin to a point two or three inches below. The voltage should be applied between the foil and a wire around the neck of the insulator, or, preferably, between the foil and a piece of wire representing the line wire and tied to the insulator as it will be in practice. The recommendations of the Introduction as regards the angle at which water should be sprayed, is all right, if this angle be uniformly adopted in testing; but some definite angle should be adopted, as the angle makes considerable difference in the voltage at which the current will arc from the line wire to the pin. The recommendations in

regard to the spray are not, however, so specific as could be desired. The amount of water sprayed, as well as the angle, makes a difference in the arcing voltage. Some time ago I endeavored to obtain from the United States Weather Bureau information as to the most violent precipitation on record in this country. The record sent me showed the most violent downpour as being about .8 of an inch in five minutes. The maximum rate of downpours during that time may, of course, have been greater than this. It has been my practice to endeavor to adjust the spray for a precipitation of one inch in five minutes. This can be most conveniently done by placing under the insulator a suitable pan and collecting in it the water for five minutes. Care must be taken that in placing the pan it does not receive water from any part of the cross-arm other than that just over it. The question of the method of obtaining the spray is one which it is well to consider. It is no easy thing properly to adjust the spray from an ordinary garden spray-nozzle or rose-spray and it is no wonder that uniform results are not



Parts of Iron-Pin Insulator.

easily obtainable. It is desirable, if possible, to have some special form of spray-nozzle which will give a uniformly distributed spray. This might perhaps be in the form of a very large rose-spray of a foot or more in diameter.

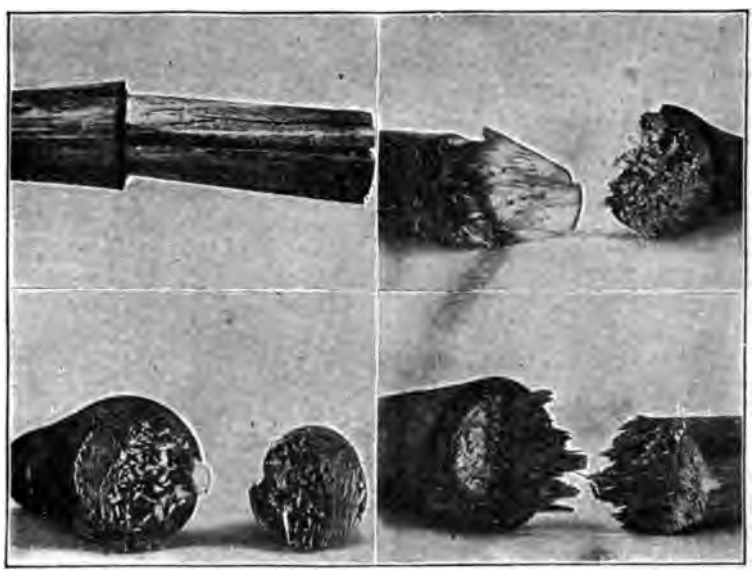
It is desirable that if possible we arrive at some definite decision this evening on the points mentioned in regard to the methods of testing insulators, so that recommendations can be made on this subject to the Standardization Committee.

VICE-PRESIDENT SHELDON:—There is a written contribution on this subject from Mr. W. L. Waters, of Milwaukee, Wis.

MR. W. L. WATERS:—The form of potential wave given by modern alternators differs very little from a sine wave. The worst case commonly met with is that of a three-phase alternator wound for high voltages. These machines have usually three slots per pole, and the wave form shows pronounced harmonics of five and seven times the fundamental frequency, but the effect of this distortion on breakdown voltage of an insulator is inappreciable. The only commercial machines that have wave

forms which would affect the accuracy of the results to any extent are the old single-phase revolving armature machines with projecting poles on the armature, which show a pronounced third harmonic. But these machines are seldom met with now. The charging current in a test on insulators or an overhead line generally conforms more or less to the potential wave form of the alternator, and whether the current is lagging or leading the distorting effect on the wave form is slight, and with all ordinary excitation and loads on the alternator the effect on the insulator test will be inappreciable.

Generally speaking, an insulator will stand momentarily a voltage strain which, if continued long enough, will break it down;



1. Pin Split in Shank and Broken at Cross-Arm.
2. Pin Broken at Upper Part of Shank at Cross-Arm.
3. Pin Broken at Upper Part of Shank at Cross-Arm.
4. Pin Broken at Upper Part of Shank at Cross-Arm.

and this time effect is most marked in solid insulators. A gas such as air does not show this. When air is going to break down under a given strain, it will do so almost as soon as it is applied, except where the insulation of the air is subsequently weakened by a violent brush discharge. Solids show this effect to the greatest extent, and liquids such as oil to a lesser extent. And I have found that in insulating materials where this effect is most marked, differences in wave form have little effect upon the breakdown voltage; it seems to be the mean voltage or possibly the r.m.s. voltage which decides the breakdown. In air the wave form has quite an appreciable effect, and the difference between a peaked wave and a flat wave may be as much as

20 per cent. of the sparking distance. Porcelain insulators show very markedly this time effect; they will stand a much higher potential if applied instantaneously than they will if applied continuously, and as far as can be seen from the experiments I have made, they appear to conform with the rule mentioned above, and are practically unaffected by wave form. The sparking distance in air, on the other hand, being considerably affected by wave form, shows at once the unsuitableness of using a spark gap as a voltmeter if there is any doubt about the wave form. And I have found that unless it was in the hands of a very careful and experienced man, a spark gap was not of very much use in accurate work. Using needles as electrodes, the voltage seems to vary so much with the condition of the points, the state of the atmosphere, the proximity of other high tension conductors etc., that consistent results cannot be obtained in ordinary work. Using amalgamated brass balls, one inch in diameter, gave better results, but they are far from satisfactory. I think there is only one really satisfactory way of measuring high voltages, and that is by means of a voltmeter transformer connected straight across the insulator being tested. This method is accurate and is direct reading, and there is no chance of mistake and no continual trouble fixing and adjusting your spark gap. Reliable voltmeter transformers can be made for all ordinary voltages for a few hundred dollars, and the use of one would save its cost in worry and hard work in a very short time.

The above remarks are, strictly, only applicable to voltages up to 50,000, as I have had no experience with higher voltages. But I think that with slight changes they will apply to the highest voltages at present in use.

VICE-PRESIDENT SHELDON:—We will now take up the paper by Mr. P. M. Lincoln, entitled, "Transposition and Relative Location of Power and Telephone Wires."

Mr. Lincoln read his introduction (see page 245), and the following contribution by Mr. M. H. Gerry, Jr.

MR. M. H. GERRY, JR.:—Mr. Lincoln has discussed the most important requirements of telephone construction in connection with high-tension transmission lines. There is no especial difficulty in installing a successful telephone circuit which will give satisfactory service and reasonable safety in operation on a pole line carrying from 50,000 to 60,000 volts.

Mr. Lincoln has mentioned the principal requisites of successful design, which are a proper adjustment of the capacity, a maintenance of high insulation from ground, and a complete transposition of the telephone wires in reference to each other, to the power circuit and to the ground. In addition, might be added the use of certain safety devices, which reduce the danger in handling telephones connected with circuits on high tension pole lines.

In regard to transpositions: Mr. Lincoln advocates the transposition of the telephone wires only, but it is desirable also to transpose the main power circuits, in order to reduce to a mini-

mum the voltage to ground on the telephone circuits. But few transpositions of the power circuit are required, and the service as a rule is materially improved thereby. Where there is considerable lightning, arresters should be installed on the telephone circuits of a design similar to those used on lighting circuits. The ordinary telephone lightning arrester is an undesirable and unsafe piece of apparatus for this purpose. Fig. No. 7 is a sketch of a telephone arrangement devised by the writer, which will give excellent results in service. Especial attention is called to the short gaps across the line, to the location of the lightning

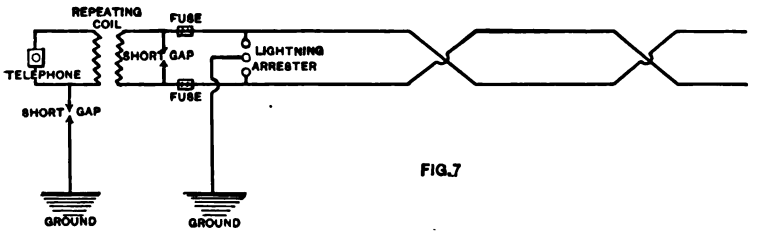


FIG.7

arresters, and to the repeating-coils, which should be insulated for at least 5,000 volts, and may be immersed in small glass jars containing transformer oil.

The Missouri River Power Company, with which the writer is connected, regularly maintains a very satisfactory telephone service on its 50,000 volt transmission lines between Canyon Ferry and Butte, a distance of sixty-four miles, and this service is rarely interrupted, even during the most severe lightning disturbances. Under normal conditions, there is no potential on this telephone line, and only the slightest hum can be detected.

MR. LINCOLN:—There is one point upon which possibly my discussion is not quite clear, and that is in regard to the transposition of the power circuits. I have stated that it is not of very great importance. My reason possibly is not very clear in the paper, and it is this—a telephone line ought to be so made that it will at all times operate, even if one leg of the power line is dead grounded. If it is made to operate under these conditions it will operate under the normal conditions of an untransposed power line, because the normal static potential induced in the telephone line by an untransposed power line is vastly less than that which will be induced in the telephone line by grounding the power line; so that if the telephone line is installed so as to run under grounded conditions, that is, with the power line grounded, it will certainly run with an untransposed power line.

VICE-PRESIDENT SHELDON:—The subject is now open for general discussion.

MR. RALPH D. MERSHON:—The truth of the observations of paragraph (6) is not clearly evident to me. The relation between the telephone circuit and the power circuit is, as stated in paragraph (4) such that in their electromagnetic relations they con-

stitute a transformer—an air-core transformer and one having very poor regulation. This transformer has in its primary—the power wires—a current unaffected in value by any current in the telephone wires and which may therefore for any given condition of power load be considered as a constant current. If the telephones took any appreciable amount of current, an amount comparable to the power current, we should have a tendency toward constant current in the telephones. If, as is the case, the telephones take a current very much less than the power current, we will have a tendency for constant voltage.

Electrostatically, each telephone wire is a plate of a condenser, the power wires being the other plate. These two condensers are in series through the telephones and have impressed upon them a constant e.m.f. The condition here is similar to that for the electromagnetic action, in that if the current in the telephones be such as will convey a charge approximating that which the impressed e.m.f. can impose upon the condensers, there will be a tendency toward constant current; if not, as seems to me is usually the case, there will be a tendency towards constant voltage. In short, it seems to me that the conditions are about the same in the case of the electromagnetic and electrostatic disturbances. This is on the assumption that the reactance of the telephone is low relative to its resistance. If this is not the case, and the reactance is comparable to the condensance concerned in the telephone circuit, then the current conditions may be almost anything, depending upon the relations between these two quantities Further, if by telephones of various resistances it is meant to designate telephones of various numbers of turns in the transmitter, then it seems to me the statement in regard to the disturbing ampere-turns is incorrect. The resistance of a coil varies as the square of the number of turns (assuming the same space available in each case for copper). The ampere-turns on constant e.m.f. vary, therefore, inversely as the square root of the resistance. It would seem, therefore, that if, as stated above, the electromagnetic and electrostatic effects are constant potential in their nature, telephones should be wound for as high resistance as possible. This seems reasonable, as it is equivalent to saying that the telephonic e.m.f. should be kept as high as possible, which in turn is equivalent to saying that the disturbing e.m.f. should be as small a percentage of the telephonic e.m.f. as possible. In order to solve some of these questions, it is necessary to know the current and e.m.f. of telephones. I have no such data and have not been able so far to obtain them.

(7) It does not seem as though the objection given for the use of the series telephone were a valid one, since one ought not to introduce a telephone at B, Fig. 2, any more than one would connect a bridging telephone at this point. In other words, telephones, whether series or shunt instruments, should be connected at even transpositions in order to obtain the best results.

(14) It is not quite clear to me why the series telephone should

not be a satisfactory instrument. As has already been stated, the reason mentioned in (7) seems hardly a valid one for condemning it.

(15) There is another method of accomplishing this desired end of having the telephone lines as nearly as possible at the same potential as the earth, which seems preferable for the use of a grounded wire; first, on the score of simplicity, and secondly, because it may also be a means of protection against loss of life or fire. This method is that of using autotransformers connected across the telephone line at a number of points, preferably at each of the telephone stations, each having its middle point connected to ground. Each transformer should be designed so as to take a very small amount of the telephonic current, but should have wires sufficiently heavy to enable it to take, in case of a cross with a high voltage wire, a current heavy enough to operate the circuit-opening devices in the power station or else to blow a suitable fuse in the telephone circuit itself. Such a device would protect the users of the telephones from disagreable or dangerous shocks, whether due to crosses, leakage or electrostatic induction, and would also help to minimize disturbances due to grounds, etc.

MR. P. H. THOMAS:—I think that the subject of telephones on long distance power transmission lines is perhaps the most important subject we have to-night. Mr. Lincoln has given a very good statement of the fundamental principles underlying the difficulties that have been found in many cases. By exchanging experiences and making suggestions, we can probably base on these fundamental principles improved methods by which the present service can be very much benefitted. As Mr. Lincoln concludes, I think there is no doubt that the trouble is chiefly due to the electrostatic induction from the normal voltage which tends to raise both telephone wires above the earth, either positively or negatively. There will also be a momentary disturbance whenever we have a charge of a lightning arrester, or any static discharge, in the neighborhood, but that will not give much trouble as regards clearness of communication, because it is over quickly. The transposition of the transmission line is, I think, an important point practically in high-voltage transmission. As Mr. Lincoln states, a telephone circuit *should* be built to work under all conditions; for instance, when one line is dead grounded. But if it is impossible to make it work at such times, and if you can make it work smoothly when not grounded by transposing the power line, you had better transpose it, and that is the actual condition of practice.

Assuming both telephone wires are going to reach high potential above the earth, there is only one thing to do to get service at all times, and that is to eliminate the baneful effects of the high potential.

I will make a suggestion for accomplishing this purpose, which may not have much practical value, but should be worth trying.

I hope that some of the engineers who have opportunities for experimenting at hand will try it for their own and the general good. For instance, it is possible we may be able to insulate the telephone wires, perhaps for 30,000 or 40,000 volts in an extreme case, and at the end of the line put the primary of a transformer and connect the telephone to the secondary, thus making very high insulation between the primary and secondary. By this means it would be possible to protect the operator, and since static disturbances do not induce potential between the two wires, it should not disturb the speech. The same result may possibly be accomplished with condensers, by connecting two condensers in series between the two pair of wires and putting the telephone in between the condensers, not connected with the line. In this case it will probably be necessary to put a choke-coil between the condensers and ground its middle point. The charging current of the condensers will be neutralized by going through the two halves of the coil in opposite directions and a telephone winding could be taken from the same core.

Mr. Lincoln suggested carrying ground wires in close proximity to the telephone wires. This should help much and would be a good method to try, but it would probably be necessary to use insulated wire for the telephone circuit, otherwise there would be trouble from repeated grounding. One method, which would be effective, but perhaps not practicable, would be to use for each side of the telephone wire a twisted pair; one wire of the pair for the telephone circuit and the other of the pair grounded. This method would make a large capacity between the telephone wire and ground, but would not actually ground the telephone wire itself.

There is another interesting possibility for those who like to speculate. Can we not use the power transmission wires themselves for sending signals? If not for telephoning, at least for general signaling. For instance, as a suggestion, we might connect a high resistance between each wire and a common point, and connect this point to ground, and similarly at the other end; then put a high frequency generator between the ground and the common connection at one end of the line, and some kind of receiving apparatus in the other. The high frequency would prevent the transformers from taking too much current, and you might be able to signal when power was on the lines. The same thing might be done with condensers or choke-coils. The advantage of using all the wires in parallel for signaling is that if you have three or four wires burnt off, there might yet be one wire you could signal through.

Another point is, it would be possible to make temporary arrangements for signaling in times of shut-down, until the power comes. That is, when voltages go off, it would be possible to use the dead wires to make arrangements to start up again. Things are in a critical state when the power is off, and the telephone lines down, and such a system of signaling might easily be arranged.

Another thing is very important, and that is the protection of the man using the telephone. One or two fatal accidents have recently occurred to operators on the telephone circuits. They should either be insulated in a booth, or the circuits should be dead grounded, or protected through an air-gap small enough to be safe for the operators.

In regard to Mr. Lincoln's statement that telephone wires may reach as high a voltage as 20,000 volts. It occurs to me that as perhaps his statement is based on theoretical considerations, I can emphasize it by stating that I have seen this voltage in fact, in Mr. Gerry's plant. I have seen sparks from telephone line to ground which were something like half an inch long, indicating perhaps 20,000 volts, perhaps higher than that. The possibility which Mr. Lincoln describes is not at all imaginary; it is very real.

MR. C. E. SKINNER:—I wish to emphasize the last point made by Mr. Thomas, that is, the protection of the workman. The insulation of the instruments in the building has been mentioned by Mr. Lincoln. The insulation of the workman is even more important, and it is not difficult to make arrangements so that he will be well enough insulated, so that even a cross between a high potential line and a telephone line will not do serious harm. It is usually painful to receive a shock of this character, but not particularly dangerous. It has been my observation that men handling telephones on high-tension transmission lines, soon learn to be very cautious and are usually compelled to watch the surrounding material, walls, etc., when telephoning. This could be easily avoided by proper arrangements, so that the man need not touch anything which would connect him to the ground.

MR. C. O. MAILLOUX:—I would like to mention a phenomenon in connection with the charging of lines which, while not exactly within the scope of this paper, is still interesting, especially as it is a phenomenon which has puzzled me and which has puzzled others to whom I have mentioned it. I have observed the fact that the transmission line will become spontaneously charged electrostatically without being connected to any generating machinery. About a year ago, in Arizona, we repeatedly observed that the three wires of a 25 or 26 mile line would become charged spontaneously to a considerable potential under various atmospheric conditions. In Phœnix, Ariz., at this time of the year, the weather is very much the same as it would be here in June of July, except that there is no rain. The weather is usually very pleasant, quite warm in the day time—one can wear summer clothes—and it cools but very little in the evening. There are occasionally slight winds, especially over the deserts, over a portion of which the line runs. I have repeatedly observed, but during the day time only, or until early evening, that the three lines became charged electrostatically. They could be discharged by making a connection to earth, but if left

alone they would soon charge again (in 10 to 15 seconds). The three wires would always charge at approximately the same potential with respect to earth, but this potential varied, as might be expected. It depended on the weather apparently, and varied, of course, with the length of time allowed for recharging. On one occasion, when there was a heavy wind preceding a rain, the potential was so high that we got sparks an inch and a half between the lines and the ground, through spark gaps. I have repeatedly observed cases where the spark was 1/16 to $\frac{1}{8}$ of an inch between sparking points. There were no indications of lightning or storm. There have been cases where the phenomenon was observed when it was raining, (at the distant end, which is near the mountains, where it rains occasionally), or shortly after it had rained; but the phenomenon was never so marked at such times; it was repeatedly observed when there was no indication of rain whatsoever, the sun shining brightly, but there was then always some wind or slight breeze somewhere along the line. My own theory was that the charge was either caused or translated by the wind, and taken up by the wire surfaces acting as condensers. I have mentioned the matter to several physicists, but my theory was rejected, as moisture in the air is considered indispensable, and it was lacking in this case. I have not succeeded in getting any satisfactory explanation. I hope there is someone here this evening who may be able to give it.

Another interesting phenomenon which I have observed in the same climate is the fact that the lightning arrester, which is located at each end of the line, has generally a tendency to frying discharge, which is more pronounced between the lightning arrester gap of one line than of the others. It was not always the same line, but changed from one line to another. I could not determine with the facilities we had what that was due to, but I was tempted to ascribe it to some sort of electrostatic action. The three line wires were systematically transposed in building this line, so as to bring an equal length of each of the three wires in the same relation with the surface of the ground.

MR. LINCOLN:—The point has been brought up about the use of series telephone versus the bridge telephone. I know by bitter experience that the series telephone does not give very good satisfaction. I once had charge of a line on the poles of which was run a telephone line, and on that telephone line we had about fifty series 'phones scattered along over twenty-five miles, about half a mile apart. We were never able to get successful service from that system. I ascribed most of the difficulty to the fact that the talking current had to go through so many loose contacts, so many jacks, and it is almost impossible to keep so many contacts in good shape. With the bridge 'phone it is necessary for the speaking current to go through only one pair of loose contacts or jacks at each 'phone. That constitutes one great advantage of the bridge over the series telephone.

The suggestion has been made that the potential between telephone wires and ground can be reduced by introducing between them autotransformers or condensers or resistances and connecting the middle points of these autotransformers, etc., to ground.

The objection to that method, it occurs to me, is that it takes off the charging current at concentrated points. The current is induced in these telephone wires as a distributed effect, distributed along the whole length; and if you try to take it off at bunched points, there will be a flow of current in the telephone wires which will introduce an e.m.f. and probably make disturbance in the telephone. The remedy which I proposed is to run a ground wire along the whole length of the telephone wire, producing a distributed capacity which will take care of the distributed induced effect most efficiently.

MR. MERSHON:—With regard to the use of condensers on telephone lines, it seems to me we want to keep the capacity of the telephone lines as low as possible to get good operation of the telephone.

If any one wanted to signal with the power lines, it would be better to signal from neutral to ground, and receive messages at the corresponding place at the end of the line.

I do not think the objection Mr. Lincoln makes, relative to the use of autotransformers on telephone lines, that the current would be drawn off at certain points, whereas it is introduced uniformly along the telephone line, would hold, as the current is flowing in the same direction in both telephone wires, and the effects of the two currents will neutralize each other so far as the telephones are concerned.

VICE-PRESIDENT SHELDON:—We will now proceed to the consideration of the paper on "Burning of Wooden Pins on High Tension Transmission Lines," by Mr. C. C. Chesney.

Mr. Chesney presented his paper (see page 253) and read the following contribution by Mr. M. H. Gerry, Jr.

MR. M. H. GERRY, JR.:—On a certain number of high-tension transmission lines there has been burning of the wooden pins. On other transmission lines of high voltage, there has been no such burning. Where burning has occurred, it has been due to leakage of current from the surface of the insulators, coupled with resistance conditions in the pin, such that sufficient heat was developed to char the wood.

When thoroughly dry, wood is one of the best of insulating materials, and one of the poorest when containing sap or moisture. The greatest objection to it is its unreliability, due to the difficulty of removing the last traces of sap or moisture. A thoroughly dry wooden pin, fifteen inches in length, will stand indefinitely 100,000 volts pressure, while a green pin of the same length, containing sap, will break down very quickly under 1,000 volts pressure. Paraffining the pins on the outside, or coating with asphaltum or linseed oil, is of no value. If the pins

are thoroughly dry, the material in which they are dipped can be made to impregnate the entire body of the wood, thus producing a pin of high insulation. Such a pin is of value, as it reduces the static strains on the insulator and decreases the amount of leakage to ground.

In order to prevent burning of pins they should have either very high or very low resistance. With insulators having a large amount of surface leakage, such as those illustrated by Mr. Chesney, an iron pin is perhaps the only solution of the difficulty.

There is nothing especially mysterious about the burning of wooden pins on high-tension lines, as it is merely a matter of total resistance to ground and the relative resistances of the insulators, pins, cross-arms and poles. Wherever burning occurs, it can be remedied by altering the design, material or dimensions of the insulators and improving the quality of the pins.

MR. H. W. BUCK:—Referring to the point which Mr. Chesney spoke of in regard to the so-called " digesting " of pins, I have seen many pins taken from the Niagara-Buffalo transmission line where such disintegration had occurred, the top of the pins having crumbled into a white powder. We have recently had some of this powder analyzed by a chemist and it was found to be a nitrate salt. This would look as if nitric acid had been formed in the presence of a static discharge inside of the insulator by the well-known atmospheric reaction and had attacked the wood, forming the nitrogen salt in combination with the vegetable matter of the pin.

In this connection I would like to say that about six months ago we built an experimental single-phase line at Niagara, about two miles in length, and operated it continuously for nearly four months at approximately 75,000 volts. The conductors of this line were galvanized iron wire, tied to the insulators with copper tie wires. At the end of the experimental run, the galvanized iron wire had turned black to a considerable depth throughout its length. The copper tie wires had also been attacked, though not so much as the iron. This surface disintegration was not due to general atmospheric influence, for iron wire in the same place but not charged electrically retained its original bright condition. I believe that this action is also due in some way to the influence of nitric acid formed by the brush discharge around the conductor. It indicates that some trouble may be experienced at such excessively high voltages where static discharge from the line is active. This discharge probably causes a combination of the oxygen and nitrogen of the air which, with the moisture of the atmosphere, forms a film of dilute nitric acid surrounding and attacking the metallic conductor.

MR. LINCOLN:—Mention has been made by Mr. Chesney and in the communication of Mr. Gerry as to the treatment of pins. I think the treatment of pins should be with a view to making them durable rather than making them good insulators. The pins should not be relied upon as a part of the insulation. As

long as they are dry and as long as the weather is perfectly dry, they may be most perfect insulators, but as soon as rain comes and the pins are wet on the surface even, they become practically useless as insulators and the entire insulation strain on the line falls on the insulators. We should treat the pins, therefore, with a view to preserving them rather than making insulators of them.

MR. MERSHON:—It does not seem that, as Mr. Lincoln stated a few minutes ago, when the arms and pins get wet, the insulation is all in the insulators; because if this were the case, I do not quite see how the sides of the pins next to the sea should be burned, and the sides away from the sea should not be burned. It seems to me it would be the other way. If the insulator controls the current, the lower the resistance of the pin, the less burning, and when the pin is charred all over there should be less heat generated on the surface, and consequently less tendency to burn. But if the pin does to some extent control the current, the lower the resistance the greater the current over the surface, and the more likely it is to burn, especially over any part of it which has had its resistance lowered.

The path of the leakage current from wire to wire of a power transmission line may be considered as a high resistance electric circuit, derived from a constant potential source. The total resistance of this derived circuit is the series of the resistance of the three elements, insulators, pins and cross-arms. The resistance of each of these elements is that resulting from two resistances in multiple; namely, the resistance of the element through its substance and the resistance over its surface. The substance resistance of all the elements is usually high, so high in a well constructed line that it need not be considered.

The surface resistance of the three elements may or may not be high, depending upon the surface conditions as regards moisture, dust, dirt or other deposits. Suppose the surface conditions of all the elements is such as to allow considerable leakage. No harm will result to the insulator unless the leakage becomes great enough to start an arc. This is not the case, however, with the cross-arms and pins. The leakage over their surfaces, if great enough, will char all the surface over which it passes. Pins are more likely to char than cross-arms, since their surface is less and their surface resistance, therefore, higher than the cross-arms; the result being, for a given leakage current, more loss per unit area of pin surface than of cross-arm surface. Any protected portion of the pin is especially liable to charring. For, if the cross-arms and pins have their exposed surfaces pretty thoroughly wet or dirty, so that the current passes over them with little resistance, the wet or dirty portions may be little affected; but if in the course of its path the current encounters any small portion of the pin which is not wet or which for any reason has a higher resistance per unit of length, the wood may be charred at this point. Now, this is what happens when the pins burn. The insulator, the lower part of the pin, and the cross-arm have their

surface resistance lowered by moisture or otherwise, but the upper part of the pin being protected by the insulator does not have its surface resistance so much decreased; the consequence is burning of the protected surface. In some cases the inner surface of the insulator next the pin and the pin itself are so well protected by the insulator that the current, instead of leaking over the surface of the insulator until it reaches a point where the insulator and pin are in contact, jumps in a brush-discharge from the edge of the petticoat to the pin rather than follow the higher resistance of the protected surface. As a result, the pin is burnt at the point where the brush discharge strikes it instead of at or near the thread. There are apparent three possible remedies for the trouble due to charring pins.

1. Make the design and size of the insulator such that for all conditions its surface resistance will be so high as to control the leakage and keep it below a point which can harm the pin.
2. Make the pins fireproof, but non-conducting.
3. Make the pins conducting.

The remedy recommended in the introduction to this discussion is (3). It is recommended that an iron pin be used. This certainly would do away with the trouble of charring pins, but whether or not it will introduce other and more serious trouble remains to be seen. It seems to me there is a very likely chance of trouble from the use of iron pins, due to the unyielding character of both iron and porcelain or glass and their widely different coefficients of expansion. Insulating material under mechanical stress will generally break down under a lower voltage than when not strained. An insulator or an iron pin might, when installed, be put under a considerable mechanical stress or one which when first installed has comparatively little stress upon it may, due to changes of temperature, be much strained; the result in either case is increased liability to puncture.

The endeavor may be made to get around this trouble by using a wooden thread upon the iron pins, but as shown by one of the cuts in the introduction, the charring trouble may still remain if this course is adopted. If a wooden cross-arm is used with the iron pin, the seat of the charring trouble may be transferred to the cross-arm unless the pins be connected by a conductor. It would seem better to adopt the first remedy and make the design of the insulator such as to protect the pins.

MR. DE MURALT:—It may possibly interest you to know that while the general practice in America is evidently to use wooden pins, in Europe it is just the opposite. Practically all the high potential installations use iron pins, and more than that, while here very often the whole pole is treated with as little iron as possible, in Europe there are quite frequently poles constructed entirely of iron, with iron cross-arms and iron pins, and the only insulation relied upon is the insulation proper. I believe this does away with the burning of pins, cross-arms and poles. I do not think there is very much difficulty in the way of avoiding

mechanical strains, which have been alluded to several times to-night, with regard to fixing the insulator in the pin. One way to get around that is to fix the pin into the insulator by means of a cement which will take up any such strain, and in a great many installations that I know of a cement made of a mixture of litharge and glycerine has been used with, as far as I know, very good results. It seems to me that it is a very fair scheme thus to lay the entire insulation into the insulator, and then let the rest of the pole take care of itself. I know of one installation, where they are operating at 26,000 volts, using American glass insulators and iron pins and iron poles; and of another one which is using 25,000 volts, and has porcelain insulators, with iron pins on wooden poles part of the way, and iron pins in walls and on any kind of a support on the other portion of the road. Neither of these installations has given any trouble whatsoever and they are amongst some of the best high-voltage installations in Europe.

MR. PHILIP TORCHIO:—I want to suggest an explanation of the burning of the wood between the iron pin and the porcelain base in the Locke insulator shown in Fig. 3 of Mr. Chesney's paper. I wish to call attention to the fact that, if two plates are maintained at a certain difference of potential, acting as condensers and spaced at such a distance that there will be no discharge between the plates, but set near the limit at which the discharge would begin and then there is inserted in the middle a plate of vulcanized rubber, which has a higher dielectric resistance than air, right away the discharge takes place between the plates. Now, that is contrary to what might have been expected. The explanation is that before the insertion of the vulcanized rubber plate the fall of potential between the two plates of the condenser is a uniform straight line, but when we introduce the vulcanized rubber plate we alter the conditions, as we have then three condensers in series, which will distribute the total fall of e.m.f. in inverse ratio to their capacities. Therefore, this plate of vulcanized rubber acting as a condenser with a larger capacity than the same amount of air which it displaces will be charged at a smaller fall of e.m.f. between its faces than existed before, and the e.m.f. between the outer condensers will be increased and then the discharge begins. Now, it seems to me that in the Locke insulator, with double porcelain petticoats and an oak thread between iron pin and porcelain, there are present the conditions of several condensers in series which might give rise to a lack of uniformity in the distribution of e.m.f. between line wire and iron pin and cause the charring of the wood at the base of the insulator.

MR. C. E. SKINNER:—I understand that the pins used on one transmission line were selected with the utmost care, and were most carefully treated, and that they have had practically no trouble whatever in more than a year's run with a potential of over 50,000 volts. These pins are protected from the weather

by glass sleeves. We should keep in mind that this is in a different climate from many other installations, and that a cure for these troubles in one climate may not be a cure in other climates.

MR. W. N. SMITH:—In the matter of wood and iron pins, it seems to me that along with various other elements the question of cost will govern. Iron poles in this country at this time cost anywhere from $30 up, and a wooden pole of suitable size runs from perhaps $7 to $20, according to size and where it can be obtained. The size of cross-arms may be governed to some extent by the size selected for the butt of the pin. If you determine first on the size of the shank of the pin that enters into the cross-arm, that in a measure determines the thickness of the cross-arm, if of wood and larger than usual. That may mean quite an additional percentage to the number of feet of lumber to be bought to provide cross-arms for a long pole line. Lumber is higher than it used to be, so that there are considerations, commercial as well as techincal, that these various elements of design all enter into. The cost of selecting some particular pin because it looks a little better may thus run into some thousands of dollars on a long pole line.

VICE-PRESIDENT SHELDON:—We will now give Mr. Chesney an opportunity to close the discussion on his paper.

MR. CHESNEY:—I was particularly interested in Mr. Buck's information concerning the cause of the " digesting " of the pin. This has bothered me on a number of transmission lines. I attributed this trouble to the formation of ozone. If it is due to the formation of nitric acid, I am glad to know it. As far as I know, on the particular line on which the Locke iron pins with wooden threads were used, the burning was not serious. The thread was punctured at one point but was in no other way injured. In order to relieve the mechanical strain between the iron pin and the insulator, I think it is quite possible to use a lead thread. Litharge and glycerine have been used to some extent in this country to cement iron pins in porcelain insulators, but lately Portland cement has been used with quite as good results. I understand that one of the largest new transmission lines in Mexico is to be built with iron pins and porcelain insulators. The pins will be cemented in the insulators with Portland cement. Instead of iron poles, iron towers will be used, placed 400 or 500 feet apart.

VICE-PRESIDENT SHELDON:—We will now close the meeting by having a paper from Professor W. S. Franklin, entitled, "Model Showing Distribution of Electromotive Force and Current along a Single Phase Alternating Current Transmission Line." (See page 261.)

PROFESSOR FRANKLIN:—I feel like apologizing to you for taking up your time at this late hour, so I will not take the time to read the statement given in the paper, but will simply exhibit the model itself.

(Prof. Franklin then exhibited and briefly described the model.)

The meeting then adjourned.

A Note on Line Insulation for High Voltage.

[COMMUNICATED BY M. H. GERRY, JR.]

The maximum practicable limit of pressure on transmission lines has been frequently stated as fixed at a certain voltage, but this limit has as frequently been extended, with good results. At the present time, no considerable difficulty should be experienced with 100,000 volts, and there is no good reason to fix the limit at that figure.

The problems of insulation are becoming better understood, but there is still much to learn. The capacity and the surface effects of line insulators have received but little attention from engineers and many of the failures are due to this fact. The form of the insulator and the material have not, in general, received the proper treatment. A desirable insulator for high-tension is not merely a piece of glass or porcelain arranged to shed rain, and of sufficient thickness to resist puncture.

The materials for construction of insulators are not so limited as assumed in the past. Glass and porcelain have been used almost exclusively, but from the experiments of the writer the material of greatest promise for high-tension insulators is prepared paper. Organic material, such as paper, has great advantage and is well suited for this purpose. Compound insulators in which the petticoats and water-sheds are made of metal, and the core of glass, porcelain, paper or other insulating material, are also feasible.

For moderate tensions, up to perhaps 30,000 volts, insulators having metal tops and outer petticoats are not only perfectly feasible, but are very desirable, and can be made very strong and practically indestructible, and much superior to the common glass or porcelain types now in use. For high voltages, the entire insulator can be made of prepared paper, or of a combination of paper with glass, porcelain or other insulating materials. Insulators on these lines may be designed for almost any desired pressure obtainable with commercial transformers, provided that all the conditions are properly understood in advance.

The writer has tested and experimented with nearly every type of insulator manufactured and with many special forms and constructions, and his conclusions, as stated above, are based on this experience, coupled with that gained from the practical operation of the highest voltage transmission in commercial service to-day.

[COMMUNICATION AFTER ADJOURNMENT BY W. N. SMITH.]

An important matter that has not been touched upon in this discussion is the design of the pole-top pin, which, on a single three-phase transmission line, is of equal importance with the cross-arm pins. As in other details of line construction a variety

of methods has been followed, of which some are doubtless better than others as regards their mechanical features. In the construction that has come under my observation, either the top of the pole has a hole bored vertically to receive a bolt or the shank of a wooden pin, or else a so-called " ridge iron " has been lag-bolted to the pole top, with the usual wood or porcelain fittings for carrying the insulator. Sometimes an ordinary oak bracket is framed into the top of the pole, the roof of which is shaped to accommodate it.

Without entering into a discussion of the relative merits of these or other methods, it seems to me that there is enough difference between all the methods in vogue to warrant an attempt at standardization. This subject would, therefore, seem to be a proper one for the careful consideration of the Committee on High-Tension Transmission.

[COMMUNICATION AFTER ADJOURNMENT BY J. R. ARMSTRONG.]

Relative to the discussion on " Insulator Pins for High-Tension Transmission Lines," the iron pin seemed to be spoken of favorably by a great many present, but to me this iron pin has one great disadvantage (leaving the difference of coefficients of expansion of glass and iron out of the question)—nearly every pin has a burr on the end, due to the way in which the ordinary pin is manufactured.

Now, there is a tendency to a continual discharge between the line and this burr or sharp point on the other end of the pin. This, after a time, cuts through the glazed finish of the insulator, and consequently causes the breaking down of the insulator.

Also in the same discussion, one of the objections raised to the use of wooden pins was that of the corroding at the ends and sides.

I would just like to raise the question: if nitric acid is formed as was suggested, could not some base be used, which would form a neutral salt with nitric acid, the pin being treated in some way with this base.

[COMMUNICATION AFTER ADJOURNMENT BY F. S. WOODWARD.]

During the discussion relative to the breaking down of insulators and the burning of high-tension insulator pins, one possible cause of the trouble was not stated. It may sometimes be due to the method of fastening the tie-wire to the insulator. In many cases I have known linemen in making what is known as a pigtail tie, after the wire was finally twisted, to bend down the end of this pigtail so that it came in contact with the surface of the insulator at a point near the lower rim; the distance between the edge of the rim on the insulator and the end of the tie, depending, of course, upon the tie's length. This would reduce the amount of creepage surface between the pin and the tie-wire, which partakes of the line potential. In this connection it might be well to state that in some cases spun-yarn, thoroughly saturated in tar or asphalt or in P. & B. paint, makes a good substitute for tie-wire, the coating practically protecting the spun-

yarn against weather effects. It might not, however, be serviceable upon a line under the conditions of voltage as described by Mr. Buck, where the surface of the line wire and of the ties showed signs of reaction due to the formation of nitric acid, which would probably affect the vegetable fibre of the spun yarn in the manner indicated in the case of the thread of the insulator pin. I regret that Mr. Buck did not state the size of the iron wire used on their experimental 75,000 volt line. I recall the paper published in the TRANSACTIONS on the "Dielectric Strength of Air," by Mr. Chas. P. Steinmetz, in which he gave an account of a number of experiments on the sparking distance between sharp points, between spheres of various sizes and cylinders of various sizes. The lower portions of the curves, as I recall, departed more and more from the straight line effect as the voltage was reduced and radius increased. It would be interesting, in this connection, to follow out these experiments and see whether a change in the diameter of the wire (practically being a continuous cylinder) would stop sparking or brush discharge at the desired voltage. For instance, if the wire in Mr. Buck's experiment was a No. 8 and the wire in the second experiment was a No. 1 or a No. 2, if the increased radius would so modify the curve that the brush discharge and the probable formation of nitrogen would be prevented.

As a sequel to the discussion on pins and insulators, it would be a very desirable thing to take up and standardize the cross-arm to which these pins are attached. Also that the distance between wires and the most desirable method of spacing same should be outlined in the report of the Transmission Committee.

COMMUNICATION AFTER ADJOURNMENT BY HENRY FLOY.

Fearing that the remarks of some of the speakers may have left an erroneous impression as to the potential of telephone circuits carried on the poles of high-tension transmission lines, I desire to state that some measurements made by a Weston voltmeter between the conductors of a telephone circuit placed five feet below the conductors of a 25,000 volt overhead circuit and ground, showed the potential to be only from 140 to 160 volts. Similar measurements on a telephone circuit three feet below a 10,000 volt line showed only about 95 volts to ground and, naturally, no difference of potential between the telephone conductors. It seems to me that the voltage of a telephone circuit given as 20,000 by Mr. Thomas cannot be such potential as would be indicated by a voltmeter or such as would cause particular damage, being, I assume, simply static potential.

Referring to the suggestions made as to signaling in case of partial breakdown of the telephone system, it has occurred to me that as a relay to the telephone circuit, a system of wireless telegraphy could be installed without large expense, which might advantageously be used in transmitting signals in case of trouble with the telephone circuit.

Discussion at Minneapolis, Minn., April 3, 1903.

The Minnesota Branch held its 11th regular meeting Friday, April 3d, at the Electrical Building at the State University. Six members and 13 visitors attended.

The meeting was devoted to the four papers of the Transmission Committee. The papers were read, and produced considerable discussion. Prof. D. C. Jackson, of Wisconsin State University, and Dean F. S. Jones, of the Engineering Department of Minnesota State University, were present. The opinion of the members regarding the papers and new ideas brought forth were:

1st. That the proposed standardization of pins and pole construction must consider not only the transmission voltage, but particularly such local conditions as mist and dampness at inland lakes and from the ocean, of salt storms, the amount of lightning, etc.

2d. Regarding wooden pins, that trouble from same must be expected in time, say after fifteen years' service, when the pins have weakened mechanically. An iron pin would seem to be more permanent.

3d. That wooden pins should not have a shoulder just above the cross-arm. The use of a shoulder produces additional mechanical strains in the pin at the cross-arm or shoulder not considered in the formula or theoretical basis given by Mr. Mershon. The shoulder was considered a relic from telephone lines and not necessary or advisable where there are heavy mechanical strains.

4th. That in service, the great majority of the insulator failures were mechanical and were due to strains produced by a poor fit between the pin and the insulator. Manufacturers of porcelain and glass insulators in the States produced excellent insulation, but the threads were not of uniform size in each and every insulator, as in those made by foreign manufacturers. The best workmanship is also desired in cutting the iron or wooden threads of the pin.

5th. That transmission lines as a whole—the pole, arm, pins, insulators and power circuits—have many weak links, in a long line. It is advisable where there are two or more companies, possibly competing for the power business of a city, to have connecting circuits and even to operate their lines in parallel. A somewhat similar arrangement is common among steam railways. A competing road gives the use of its tracks to a rival during temporary trouble to roadbed or at a burned-out bridge. A working arrangement of this nature, *i.e.*, to assist each other as far as possible in times of trouble, would help the reputation of power transmissions.

DISCUSSION AT SCHENECTADY, APRIL 7, 1903.

DR. F. A. C. PERRINE:—There is so much in these papers, that it is hard to enter upon a discussion of them. In regard to the paper by Mr. Mershon, I believe that there is one element in the strength of the pin which he has altogether neglected, which however, may possibly be neglected on account of the roofing or rounding of the cross-arm. I refer to the element of strength in the shoulder. The pin is discussed as a beam fixed at one end, and in consequence the ordinary parabolic section of the beam is brought out, because the fibers of the pin are considered to be in tension or compression. Now, as a matter of fact, if the shoulder is made pronounced and firmly fixed on the cross-arm, the pin is very much increased in strength; because there is an element of the stress applied to the end of the pin, which is transmitted parallel to the side of the pin and against the cross-arm.

Mr. Mershon says that usually pins break off at the shank. This is generally the case where pins do not bear on their shoulder in the cross-arm. In some experiments made in the West with a number of pins, I found that if the pins were given a proper shoulder and made to bear in the cross-arm, they did not break at the shank, but broke diagonally from a point about at the end of the thread crossing the pin. The pins that were tested were approximately the same locust pins that were mentioned in the discussion. By giving these pins a proper bearing, the strength was found to be increased from 700 lbs. to 900 or 1,200 lbs., with approximately the same pin.

I notice that the pins designed by Mr. Mershon correspond very closely to the pin in Fig. 1 in Mr. Chesney's paper. Furthermore, I see that the pin in Fig. 1 in Mr. Chesney's paper is not given a bearing in the cross-arm, as the shoulder is filleted so that it does not come down to a solid bearing. The other pin in Fig. 2 is given a solid bearing, and this pin is very much stouter than the pin in Mr. Mershon's paper or the pin in Fig. 1. As you will notice, these pins are both for the same insulator. The pin in Fig. 1 is the pin used on the Standard Company's lines and in Fig. 2 the pin used on the Bay Counties lines. Mr. Hancock of the Bay Counties Company designed this pin after testing a number of pins and insulators. He found that the pin in Fig. 1 would almost invariably break before the insulator; that the pin in Fig. 2 would practically never break before the insulator, this pin having practically the same strength as the insulator. The material is eucalyptus. Since the discussion, Mr. Hancock has reported that the strength of this eucalyptus pin compared with a steel wagon-axle. The axle was broken at a strain that would not break the insulator, although the wood pin was of approximately the same strength as the insulator.

The observation made in the discussion that Mr. Mershon's pin is based on a uniform stress applied to the insulator, and that this is not a reasonable specification for the standard pin, is a point that is very well taken. With lines such as are proposed

now, with spans of five or six hundred feet, the transverse stress on a wire from one-half to three-quarters of an inch in diameter, will be in excess of 600 lbs. With oak or locust, as specified by Mr. Mershon, the pin will not have a strength much in excess of 600 lbs. With ecualyptus, it would have a greater strength, eucalyptus having approximately the strength of good hickory. In such spans of five or six hundred feet it would be necessary to install more than one of Mr. Mershon's pins to stand the strain from heavy cables.

In regard to the testing of glass insulators, so far as I am aware,having had experience with a good many thousands of glass insulators, the puncture of glass insulators by reason of breakage after the insulator had been inspected visually and tapped with a mallet, is very unimportant. The point that Mr. Blackwell makes of glass insulators breaking down, due to lack of annealing is, on the contrary, an exceedingly important one. One of the lines in California installed a type of glass insulator that had been well tried, but apparently it received a batch of unannealed insulators, for before the end of the year a large number of their insulators separated and broke down; the head of the insulator cracked off and let the wires drop. Such occurrences with glass insulators, are far more important and more likely to happen than punctures. A glass that will puncture at all, I believe to be a glass that is so bad that you could see the defects. No insulator should be installed which has a bubble between the wire and the pin, because these bubbles are vacuums and you might as well have just so much metal in the insulator.

Mr. Lincoln's paper, is I think, the first approaching a complete discussion of the telephone line transposition problem, and it is so complete that I cannot sit down without commending it, without saying that in my belief it contains the elements of the entire solution of this very important and difficult problem. Had this paper been printed four years ago, I believe that I know of more than one man's life that would have been saved by it. A very sad accident happened about a year ago: A patrolman starting out to work, went to the closed telephone box to report. In connecting this telephone to the line, he was killed. I believe the power line was grounded, but not to the telephone line. Since that, the company has observed the rule of seeing that the operator is insulated as well as the line.

The question of potential to earth is the only thing that Mr. Lincoln has not given an absolute statement of, and I am inclined to think that that is because there is something in it that we don't yet know. Mr. Lincoln writes of the difference of potential, but says that that represents so small a current as to be inappreciable If the surface of the condenser that is produced by the power line and the telephone line and the condenser of the telephone line and the earth is calculated, where the line is one or two hundred miles long, the amount of current that is transmitted will not be by any means inappreciable, and will be enough to give a great

deal of trouble. This is the only criticism that I would have to offer to this most excellent paper of Mr. Lincoln's.

This model of Prof. Franklin's is a piece of education to all of us, not simply as a model of electromotive force, but because it represents the effects that take place where we have a line of one complete wave length.

DISCUSSION AT PHILADELPHIA, APRIL 6, 1903.

MR. HODGES:—A few items of particular interest were brought out in the discussion at New York, so I will quote from that discussion.

MR. HODGES:—Mr. Gerry wrote, "There is no special difficulty in installing a successful telephone circuit, which will give satisfactory service and reasonable safety in operation, on a pole line carrying from 50,000 to 60,000 volts." With this I heartily agree, and many would undertake to install a successful system in connection with any present high-tension transmission line without the slightest doubt of success. It simply amounts to taking the necessary precautions to have the line properly ballanced, insulated and protected. But I cannot agree with Mr. Gerry that "the ordinary telephone lightning arrester is an undesirable and unsafe piece of apparatus for this purpose," —referring to a location "where there is considerable lightning." Of course, he says *ordinary arrester*, and this brings up the question to what arrester does Mr. Gerry refer? I have had considerable experience with different types of arresters and I have found that under the conditions mentioned by Mr. Gerry, some arresters are better than others. Unfortunately, we do not know just how a lightning discharge will act in every case. Lightning discharges are freakish, but a properly constructed telephone system will be as safe as anything possibly can be. Of course, the *ordinary* telephone lightning arrester would not be sufficient in *extraordinary* cases.

Mr. Mershon stated that the truth of the observations of para-

graph (6) of Mr. Lincoln's paper was not apparent to him. Referring to the first portion of this paragraph, in which Mr. Lincoln says that comparing the electromagnetic and the electrostatic disturbances in the section of untransposed telephone lines, the first is in the nature of constant *potential* effect, and the second in the nature of constant *current* effect.

Mr. Mershon agrees that the electromagnetic disturbance is in the nature of constant *potential* effect, but does not agree that the electrostatic disturbance is in the nature of constant *current* effect, excepting only when the static charge carried by the telephone circuit approximates that which the power line can impress statically upon the telephone lines. This is not actually the case in practice, so the electrostatic disturbance is also in the nature of constant *potential* effect. Therefore both effects are of the same nature, " that of constant voltage under actual conditions."

Mr. Lincoln's view of this matter seems to me to be that as the electrostatic charge on the two telephone wires is not independent of the resistance of the telephone circuit, an increase in the resistance of the circuit will increase the electrostatic charge to the telephone wires, and this increase of charge will tend to overcome the increased resistance and maintain a constant current effect.

However, in any particular instance the resistance will remain constant, and I agree with Mr. Mershon that both the electromagnetic and electrostatic disturbances would be in the nature of constant voltage effect.

Mr. Mershon further said that the statement of Mr. Lincoln's with respect to the disturbing ampere-turns was incorrect, " if, by telephones of various resistances, it is meant to designate telephones of various number of turns, assuming the same space available for copper in each case." Mr. Lincoln says that " with telephone receivers of varying resistance, the ampere-turns in the receiver due to electromagnetic induction, are particularly constant, while those due to electrostatic induction increase with the number of turns and, therefore, with the resistance of the receiver."

Mr. Mershon's objection is that with constant poltential the ampere-turns are not constant as the resistance increases, as the ampere-turns vary inversely as the square root of the resistance. I agree with Mr. Mershon in this, but perhaps Mr. Lincoln does not refer to the increase in ampere-turns under the assumption that only the same space in each case is available for copper.

I would say, however, that while the electromagnetic induced e.m.f. is independent of the resistance and the electrostatic induced e.m.f. is dependent upon the resistance, the effect of both upon the receiver is dependent upon the number of turns of the receiver; the electromagnetic induction by reason of the number of turns and the resistance, and the electrostatic induction for the same reasons and also because of the effect upon the electrostatic e.m.f. by the change in resistance, when the resistance is low

And so, comparatively, the electromagnetic disturbance in general is more greatly reduced by an increase in the resistance of the receiver on a similar coil, than the electrostatic disturbance.

Mr. Mershon said that from the above conditions it would seem advisable to wind the receivers to as high a resistance as possible, in order to overcome the electromagnetic and electrostatic disturbances. This is evident; but assuming that the ordinary telephone receiver for various reasons is as large as desired, there is a mechanical limit to the increasing of the resistance.

It has been supposed throughout that the receiver is connected in the line direct. This, however, is rarely the case. Most often the receiver is connected to one side of a transformer (or "repeating coil," as we term it), and the other side of the transformer is connected in the line. This transformer could be built to any desirable size and resistance, particularly as it is advantageous to raise the potential in transmitting, and therefore the number of turns of the winding connected to the line may be large.

Mr. Mershon said that the objection given for the use of the series telephone by Mr. Lincoln does not seem a valid one, as no one would connect either a series or bridging telephone at a transposition point. In his paper Mr. Lincoln has only taken the worst point as a sort of " horrible example."

I would say, however, that from consideration of the static disturbance, which is twenty times or more greater than the induced current disturbance, a series instrument could not be connected in the line without throwing the system out, except at certain points; and these points are the ones from which no induced charge is flowing towards a transposition point. Moving the instrument from these neutral points towards the transposition points, would simply be going from good, through bad, to worse. An instrument bridged across the line would not be disturbed to any extent as a path of least resistance would be toward the transposition point, and not through the coils of the instrument.

In the discussion, Mr. Lincoln attributes his trouble with series instruments largely to the points of contact. This could easily be a cause, but the principle trouble would come from the above-mentioned static disturbance. Mr. Mershon suggested a method of accomplishing the desired end of having the telephone lines as nearly as possible at the same potential as the earth, which, he says, seems preferable to the use of a ground wire suggested by Mr. Lincoln in paragraph (15). Mr. Mershon's method is that of using auto-transformers connected across the telephone line at a number of points, preferably at each of the telephone stations, each having its middle point connected to ground. He goes on to say that each transformer should be designed so as to take up a small amount of telephonic current, but should have wires of sufficient size to enable it to take, in case of a cross with a high voltage wire, a current heavy enough to operate the circuit-opening devices in the power stations, or else to blow a suitable fuse in

the telephone circuit itself. If the transformer designed to allow a passage of sufficient current to blow a fuse would also prevent the passage of the telephonic current, it appears to me that the idea is a good one. But, referring to the case where the power circuit is of high frequency, the transformer coil which would prevent the passage of the telephonic current would also retard the passage of the power current, and it would be necessary to protect the telephone user and open the line by other means.

Mr. Thomas suggested that probably the increasing of the capacity between the ground and telephone wires might best be accomplished by using a twisted pair, one side of which is connected to the ground, for each side of the telephone circuit; and having this properly insulated would prevent the danger of a cross such as would be likely to occur. Mr. Lincoln's scheme is that a wire connected to the ground be run in proximity to the telephone wires, all of which, presumably, would be bare. Mr. Thomas's idea would be carried out at less expense by using triple conductor-wire. Of course, if a lead-covered cable would be used, the grounding of the sheath would carry out Mr. Lincoln's idea completely. This, however, would increase the expense of the line considerably.

All these methods of bringing the ground near the telephone wires would make it much more liable for a workman to ground the telephone wires through his body, and therefore, as suggested by Mr. Thomas, he should be protected by having, between the telephone circuit and ground, an air gap small enough to make it safe.

Mr. Lincoln's objections to the introducing of transformers, condensers, resistances, etc., between the telephone wires and ground are recognized by all who are particularly interested in having the telephone system work as well as it possibly can. The line should have as little leakage as possible and the capacity of the telephone lines should be kept as low as may be. Therefore, to obtain the best transmission with the greatest safety, it would seem that the following points should be carefully considered.

First:—Both power and telephone lines should be properly transposed. And this transposing is not altogether so simple a matter as it is generally supposed, as it would be possible to arrange the transpositioning so that the power and telephone wires would neutralize each other.

Second:—The insulation of the telephone lines should be high, and of course the line should be strongly constructed.

Third:—At each telephone station the instrument circuit should be connected to the secondary of a transformer. This transformer should have a high resistance primary with a great number of turns, and the insulation between the primary and secondary should be high. The middle point of the primary should be connected to ground through a retardation or choke-coil. In each side of the telephone line circuit, at each station, there should be a so-called " lightning gap " arranged, designed

so as to discharge when the potential of the telephone wires should approximate that which would break down the insulation of the line.

In the connection to ground of this lightning arrester, there should be placed an electromagnet of low resistance and low retardation; so arranged that by its operation it will open the telephone line between the arrester and transformer and connect the ground side of the lightning arrester with the ground direct.

This method of construction removes the objection that a workman would come in close proximity with the ground while working on the telephone circuit. And also it provides necessary protection for the telephone user without allowing a path for leakage of the telephone current, or affecting the transmission by increase of capacity.

MR. LINCOLN:—In reference to the telephone business, it has been the general experience that as long as no trouble occurred on the main transmission line paralleling the telephone line (or rather which the telephone line parallels) the service on the telephone line can be carried on with practically no difficulty. As soon as the main line gets into trouble by grounding, and so on, there is difficulty on the telephone line—it becomes very noisy and practically inoperative. That is just the time when the telephone line is most important; when there is trouble, you want to use the telephone line.

CHAIRMAN HERING:—We would be glad to hear from some of the insurance men.

WASHINGTON DEVEREUX:—Naturally, insurance people are not in favor of high-tension currents beyond five hundred volts. High-tension has come to stay. In the early days I think the electric light people frightened the insurance people very much. The subject is now in safe hands and being considered in conjunction with the Committees of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the National Board of Fire Underwriters, and I think very soon there will be rules formulated permitting sixty thousand volts. Those rules have not yet been published, and what they are I don't care to say.

CHAIRMAN HERING:—I wish to call attention to a limitation of the formula of Mr. Mershon, which is, I believe, the well-known formula for beams. While it is correct, it should be understood that it applies only to the case in which the cross-section does not change abruptly. For instance, if in a thick horizontal projecting beam a vertical saw-cut is made, say half way through it, the beam will not be so strong as a smaller beam having a uniform cross-section equal to the remaining half. In other words, a beam of small but uniform or uniformly varying cross-section may be stronger than one of larger but abruptly changing cross-section. The shoulder of the proposed standard pin is a case of this kind, in which the cross-section changes abruptly and this changes the internal stresses in such a way that the pin may be subjected to much greater strain than this formula would give,

unless the bracing action of this shoulder more than compensates for the abrupt change of cross-section.

Mr. Mershon proposes to cut off the tops of the screw thread, as shown in his illustration; why does he not also fill up the bottoms of those V-shaped screw thread cuts, as is done in the standard thread? This would make the pin much stronger, as there is then a less abrupt change of cross-section. It would also be interesting to know why he used an angle of 90° instead of 60°, as in standard threads.

CHARLES HEWITT:—I notice that in this pin, which I believe is one of Mr. Mershon's, the bottom of the groove is flattened. It seems to be flattened just as Mr. Hering says.

CHAIRMAN HERING:—We have a number of models here that have been sent to us by the manufacturers. Mr. Sanville will tell us something about them.

(Exhibition of specimens of insulators and pins.)

MR. HUTCHINS:—I would like to ask if anyone here has had experience with benefits derived from using a dark color over a white porcelain. I have heard it said that the white porcelains make a very good target, while the dark ones are not so conspicuous.

CHAIRMAN HERING:—Someone remarked that the insulators would be liable to crack when the sun shines on them. It seems to me that the dark one would be much more liable to crack from the sun than would the light one.

MR. LINCOLN:—I think the porcelain insulators will stand the strain due to heating much better than the glass. As far as shooting is concerned, I think the brown insulators were adopted at Niagara on the last installation there for the purpose of being less conspicuous, although we had no very great trouble there.

MR. HODGES:—The question of shooting insluators is of great concern to the telephone people. A small boy seeing the insulator shoots at it and puts shots through the ærial cable, which very much disturbs the ærial cable. At Niagara it seems that small boys throw hoops over the wires, short-circuiting them and causing "fireworks."

MR. LINCOLN:—Shooting insulators reminds me of a story in reference to the lines running into the City of Mexico. They have a great deal of trouble there from the fact that the natives throw the leaves of a plant called the megalia, which is a plant consisting of ninety-nine per cent. water, over the lines, and they cause a great deal of trouble, so much that they had to get the Governor to detail a cavalry guard. One day they caught a native throwing leaves. They took him to court, proved the case against him and the judge sentenced him to a year in jail. He suspended sentence, however, until the next case of malicious interference, no matter who caused it.

MR. HEWITT:—In Mr. Sanville's abstract of the New York discussion he spoke of the "digested wood" as being fine nitrogen salts. I would like to ask whether there was any explanation as

to how these nitrogenous salts were formed, whether the air in the neighborhood was combined with the air forming nitric acid, or how that combination came about.

MR. SANVILLE:—As I understand Mr. Buck's description of this, he seems to take for granted that we all know that a static discharge in moist air produces nitric acid. It seems to be a fact he is aware of.

MR. HEWITT:—I have learned something new. I was not aware that nitrogen and oxygen in the air could be combined to make nitric acid.

CHAIRMAN HERING:—There is a plant in operation at Niagara Falls where nitrogen and oxygen are combined, forming nitrous oxide gas from which nitric acid is made.

MR. HEWITT:—There is one other point in the discussion in which it says ecualyptus pins are found the best. Naturally that would be the case in California as there are no others in the state. But it is hardly just to claim that it would be better than the locust or the oak.

MR. THOS. SPENCER:—In regard to the formation of nitric acid, even an arc, in a confined space in the presence of water will form nitrous acid. Take an enclosed lamp after burning a short time and shut it off and after a while open the cylinder; you would get a very decided nitrous acid smell. That is probably what Mr. Buck referred to.

CHAIRMAN HERING:—It seems rather a difficult thing to do to combine the oxygen and nitrogen in the air. It seems a peculiar case in which it is done unknowingly or unintentionally.

The meeting then adjourned.

DISCUSSION AT CHICAGO, APRIL 7, 1903.

The meeting was called to order at 8.20 P. M., with Secretary Pierce in the Chair and about 100 members and guests present.

The first paper, "Mechanical Specifications of a Proposed Standard Insulator Pin," by Ralph D. Mershon, was presented by Mr. W. G. Carlton.

At the conclusion of the reading of the paper, Mr. Carlton also read a discussion which had been presented in New York, by Mr. C. L. Cory, of San Francisco, and D. L. Huntington, of Spokane, Washington.

The second paper, "The Testing of Insulators," by F. O. Blackwell, was presented by Mr. James Lyman.

At the conclusion of the reading of this paper, Mr. Lyman read a portion of the discussion which had been presented in New York, from Mr. M. H. Gerry, Mr. P. M. Lincoln, Mr. W. N. Smith and Mr. C. C. Chesney

MR. CARLTON:—I remember a test made on a lot of 5,000 glass insulators, at 50,000 volts; out of that lot a very small number broke down—in the neighborhood of five, I think—and a part of the defects in the five could have been detected by ex-

amination. Of this lot of 5,000 insulators which were put in service on a 33,000 volt line only a few have broken down, and they were probably injured at the time they were installed.

MR. GONZENBACH:—I think the matter of glass versus porcelain insulators has been agitated for a good many years.

Mr. Carlton seems to be in favor of glass insulators, and in the particular instance that he refers to, I would like to ask if the glass insulator had been tested at the factory or on the ground before being put in service?

MR. CARLTON:—I do not know about that; I simply remember the results that we obtained.

MR. GONZENBACH:—I have had that question before me for about eight years, and in every plant I have been connected with this question has come up, whether glass or porcelain insulators should be used.

I was at one time connected with the building of a small municipal plant in the east—in Vermont. Every purchase was passed upon by an assembly of voters of the town, and it was interesting to hear those old farmers discuss whether glass or porcelain insulators were the better, there were some red hot arguments on both sides, but I do not know that I am any nearer a decision to-day than I was at that time. I think the disrepute of glass is very largely due to the manufacturers of it. I can only say that so long as power is transmitted over glass insulators at between 40,000 and 50,000 volts glass insulators must be considered as competitors of porcelain.

Mr. Blackwell mentions a factor of safety of about 3½ to 1, in connection with the very high pressure test, and a maximum test pressure of double the service pressure. I cannot understand why we should go quite so high. As a matter of fact I understand that Nunn Bros., in their Telluride, Utah, installation, using 40,000 volts transmission pressure, give their insulators a test not exceeding 50,000 or 55,000 volts, and are obtaining good results.

The third paper, "Transposition and Relative Location of Power and Telephone Wires," by P. M. Lincoln, was presented by Mr H. H. Wait.

At the conclusion of the reading of this paper the discussion which had been presented in New York by Mr. M. H. Gerry, Mr. Ralph Mershon and Mr. Thomas, was read.

MR. WAIT:—Mr. A. S. Hatch, City Electrician of Detroit, has had trouble on account of induction on their telephone lines, which are run on the same poles, in a good many cases, as their series arc-lighting lines. These arc-lighting lines are, of course, not of the very high potential character which we have been talking about, but the fact that they are constant current and have varying resistance in the circuit, brings up a little different problem. He has sent a communication and I will read some parts which will perhaps be of interest.

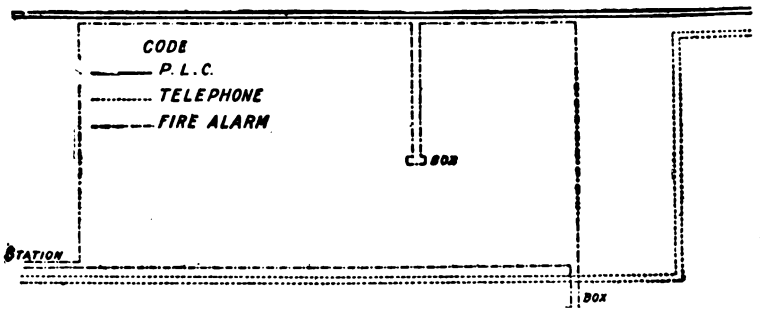
MR. HATCH:—I have been greatly interested in the introduction for discussion of disturbing currents in telephone lines par-

ticularly on account of my own experience during the past year with series alternating arc lamps supplied from circuits run, in places, on the same poles with fire alarm and police telephone systems.

When the plant of the Public Lighting Commission of Detroit, Mich., was installed, it consisted of direct-current open arc lamp, burning in circuits of 100. Two years ago in order to meet the demand for new lamp locations, it was decided to install the series alternating arc system, and the first installation was in the western part of the city, consisting of about 380 lamps supplied by six circuits from a substation which received the current from the main station by means of a two-phase feeder, thus giving three circuits in multiple on each phase, each circuit being controlled by a reactance coil. The old direct current circuits were not changed except to cut them into the substation, reduce them to 60 lamps capacity and double all single wire loops. Where convenient, at the time of installation, the lighting commission, fire alarm telegraph and police signal systems were run on the same poles. About one-half of this combined construction consists of a six-pin arm with the arc circuits occupying the middle pins and the fire and police wires on the outside, the remainder being the commission wires on an arm below the fire and police. The combination of any particular arc and fire or police circuits is only for short distances, one or the other circuit frequently leaving its neighbors on its own poles and if coming back again it may be to meet another arc circuit of a different phase. The six circuits are designated by letters. The least induction is produced when the circuits A, B and C are of one phase and D, E and F of the other, although they are so arranged that any circuit can be run with either phase. However, if C and F are cut off, the telephone lines are almost silent, showing that where the fire and police lines parallel the other four circuits, they balance themselves. This made the first problem to balance the telephone lines for circuits C and E and, at the same time, not disturb the balance already established in connection with the other four.

Having accomplished this, cleared the telephone lines from electromagnetic induction, but a change in the electrostatic capacity of any circuit would alter the conditions entirely. The alteration of the electrostatic induction is produced in three ways: first, by the leakage of both the arc and telephone circuits, due principally to dampness; secondly, by varying resistances particularly in the arc circuit; thirdly, by the disturbance due to independent parallel lines. The arc circuits, when running, will vary in insulation from 500 to 150,000 ohms between wires and ground, yet, on battery test the next day will measure over a megohm, I am satisfied from tests conducted so far that the increased induction caused by this variation can be eliminated by the proper use of condensers and inductances. The second variation, that due to a variation of the resistance of the arc circuit is entirely a lamp variation and will be corrected in the lamp.

The third disturbance, that due to independent parallel lines, is the most serious one to overcome. By independent parallel lines, I mean any wire paralleling an arc circuit and constituting in itself, a closed circuit. My attention was first called to this about three years ago. The arc circuits are grounded at the switchboard during the daytime, so constituting a closed circuit grounded at one point. If the circuit parallels an alternating line, it becomes the secondary of a transformer. In testing this circuit during the day, the ground would be taken off and the circuit opened at the switchboard. While measuring to ground I would frequently get a spark at the jack which could not be attributed to the testing battery. I have sent patrolmen out to find an imaginary cross with live wires, but two or three fruitless searches led me to realize the cause. The accompanying sketch shows this effect on telephone lines. A fire alarm wire, a police telephone line and an arc circuit are on the same cross-arm for a short distance, the fire alarm wire finally leaves the Commission's poles, and later, is carried for some distance on police poles



thus paralleling a telephone line which also parallels the same or another arc circuit. Ordinarily, the fire alarm wire is a closed low resistance circuit and so acts as the secondary of a transformer of which the arc wire is the primary, and this secondary current induces a tertiary one in the telephone wire which is out of phase with the secondary current induced by the arc current in the same line. This may be obviated by neutralizing the current in the fire alarm wire, although probably the easiest way is a new line of poles.

In paragraph 9 of Mr. Lincoln's paper he speaks of considering two condensers, one between the power wires and the telephone line and the other between the telephone line and ground. I should think the third condenser, that between the power line and ground, should be considered also, for this reason; the first condenser is practically constant, for if there is a variation of potential (especially that caused by leakage) in this condenser, the same variation is caused in the other two, so the relative inductive effect is practically constant; but either of the other two con-

densers will vary from one-half the potential between the power wires to zero. For this reason, I should think the ground wires should be so wired that their condensance can be easily altered or condensers placed at definite places, so they can be varied at will.

The next paper, " The Burning of Wooden Pins on High-Tension Transmission Lines," by Mr. C. C. Chesney, was presented by Mr. J. R. Cravath.

At the conclusion of the reading of this paper, Mr. Cravath read discussion which had been presented in New York, by Mr. M. H. Gerry, Jr., H. W. Buck, Mr. Lincoln and Mr. Mershon.

MR. CRAVATH:—It would seem to me that in the first place it is a question of getting an insulator that will not allow enough leakage of current over its surface to burn its pin; or, if you cannot fully accomplish this, of using a construction that will permit of the readiest repair in case the insulator does break down. Of course the use of iron poles in this country is practically out of the question on account of expense, but from the standpoint of quick and easy repair they are excellent. If you have to renew the insulator only you can do it quickly, but if you have to renew the whole cross-arm or whole pole, it is quite an undertaking. If you use iron pins, of course it is only removing the trouble one step farther away, for then if your insulator leaks the burning occurs somewhere else.

Mention has been made of a line in Mexico which is to use steel towers instead of a wooden pole line. The towers are to be about 440 feet apart, the idea, of course, being to cut down both the cost for poles and the number of insulators. Of course the steel tower line is a much more permanent construction than any wooden pole line could be in the matter of burning, and reduces the number of points at which insulator leakage may occur.

The trouble from burned pins near the sea is sometimes very serious. I happen to know a case where they could not even maintain a 2000 volt line at times. The mist and fog would blow in and collect on the insulators together with dust, and after a long dry spell when a rain storm came there would be a disheartening number of breakdowns from burning of the pins. They overcame the trouble by putting on some protectors or boxes simply to keep the dust and mist from drifting under the petticoat of the insulator. This box does not come up to the wire or touch the insulator, but rests on the cross-arm and protects the lower part of the insulator from dust.

Discussion at Pittsburg, April 9, 1903.

Programme.

The meeting was called to order by Chairman P. M. Lincoln.

1. Introductory Remarks.—President C. F. Scott.
2. "Mechanical Specifications for Proposed Standard Insulator Pin," by Ralph D. Mershon, read by W. K. Dunlap.
3. "The Testing of Insulators," by F. O. Blackwell, read by C. E. Skinner.
4. "Transposition and Relative Location of Power and Telephone Wires, by P. M. Lincoln.
5. "Burning of Wooden Pins on High-Tension Transmission Lines," by C. C. Chesney, read by E. M. Tingley.

The discussion was participated in by C. E. Skinner, S. P. Grace, P. M. Lincoln, H. Etheridge, C. W. Rice, Mr. Bedell, P. H. Thomas, B. Frankenfield, J. S. Peck and President C. F. Scott.

Mr. Skinner:—I have always been under the impression that for glass insulators a potash glass would give better results than a lead glass. This impression has not been thoroughly proved by test. Mr. Blackwell says that the striking distance of a given e.m.f. is greater at high altitudes than at low altitudes. If the striking distance is to be used by the Institute as a measure of the e.m.f., some figures should be obtained showing the variation of striking distances with the variation in the height of the barometer.

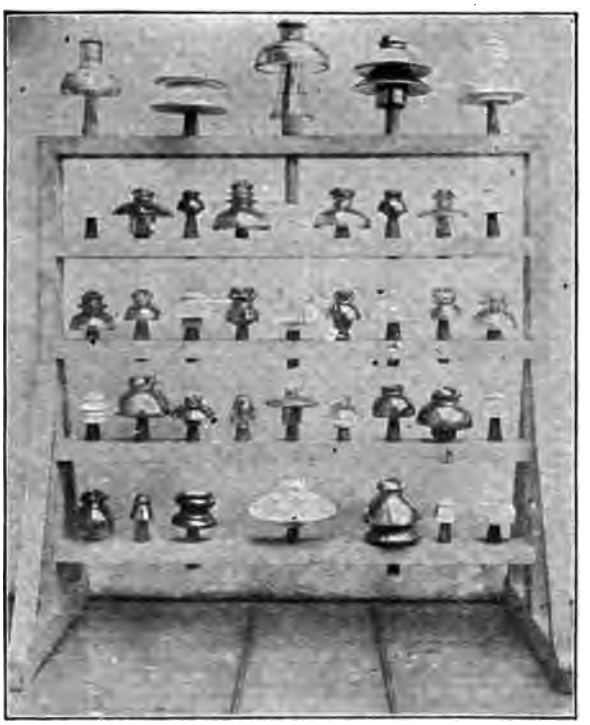
In early high-tension work the question of surface leakage over the insulator was considered of very great importance, and many of the earlier designs of insulators included an oil cup underneath to give a higher surface resistance. As far as I am aware, this construction has not been used on any of the long-distance transmission lines in the United States, and later practice has proved that such a device is entirely unnecessary. It is objectionable because it is soon filled with foreign substances and defeats the object for which it was designed.

The method of regulating the voltage of the testing transformer should receive consideration. There are three methods which have been followed, viz: first, by varying the field of the generator; secondly, by the use of a resistance in series with the low-tension side of the testing transformer; thirdly, by varying the voltage on the low-tension side of the transformer by means of a regulator dial connected to a suitable regulating transformer with a number of taps brought out from its secondary winding.

The first method can be used only where a generator is provided exclusively for this work. In the second method a water rheostat is usually employed. This gives a very smooth variation in e.m.f., and while unwieldly and requiring constant attention during the test, it is capable of giving very good results. The third method requires that the voltage on the high-tension side be changed by comparatively small steps, which may be done with proper regulating dials without opening the circuit. Steps

even as great as 5 per cent. are not considered particularly harmful in the testing of insulators.

I am pleased to be able to show you an exhibit of insulators intended for high-tension work. This exhibit is not complete by any means, but shows a number of types which are in use at the present time. Most of these insulators have been given a test which may be briefly described as follows: the insulators were placed on the standard-size pin, the pin being wrapped with tin-



foil. A photograph of the insulators (Fig. 1) as they appeared on the testing rack after a snow storm is submitted as part of this discussion. The test was made by applying the high potential from a testing transformer, the voltage of which was regulated by means of a regulator dial giving very small steps. The testing voltage was applied between a "tie" made in the ordinary manner and the tin-foil coating of the pin and the test was made under different weather conditions. The breakdown test was repeated at intervals for a period of some months, beginning about the middle of February and ending about the first of July.

In no instance did a breakdown occur through the insulator

itself, the break in every case being over the surface. The maximum testing voltage available was approximately 90,000 volts. In some instances, when the insulator was dry, no breakdown over the surface could be obtained. The following are the results of tests on certain characteristic insulators, as shown in the accompanying photographs. (Fig. 2 and Fig. 3).

No. 1—Porcelain, brown glaze:

Diameter at base	10″
Height	8¼″
Surface distance from wire to pin	22¾″
Shortest breaking distance	12″

When dry and clean, stood	91,000 volts.
During heavy, dry-snow storm, stood	90,000 "
During moderate rain storm, broke down at	86,400 "
When covered with ice and snow, broke down at	52,200 "
When dry, stood for ½ hr.	71,500 "

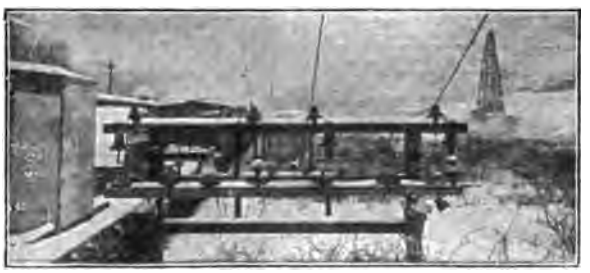


FIG. 1.

During the last test the snow was piled on the cross-arm almost to the lower petticoat.

No. 2—Porcelain, brown glaze:

Diameter at base	7½″
Height	6¾″
Surface distance from wire to pin	13½″
Shortest breaking distance	9⅝″

When dry and clean, stood	92,000 volts.
During dry-snow storm, broke down at	87,300 "
Covered with wet snow, broke down at	62,100 "
During moderate rain storm, broke down at	68,400 "
When dry, stood for ½ hour	66,000 "

No. 3—Porcelain, brown glaze:

Diameter at base	6¾″
Height	4⅞″
Surface distance from wire to pin	13″
Shortest breaking distance	7¼″

When dry and clean, stood ....91,000 volts.
During dry-snow storm, broke down at..... ...78,750 "
During moderate rain storm, broke down at ....48,600 "
Covered with wet snow, broke down at..... ....54,000 "
When dry, stood for ½ hour .....64,400 "

No. 4—Porcelain, brown glaze:
Diameter at base .... 6½"
Height .... 4¾"
Surface distance from wire to pin .... 8"
Shortest breaking distance..... 6⅝"

When dry and clean, broke down at .....73,800 volts.
During dry-snow storm, broke down at.....78,750 "
During moderate rain storm, broke down at ....53,400 "
When covered with wet snow, broke down at ...52,350 "
When dry, stood for ½ hour .....55,000 "

FIG. 2.

No. 5—Porcelain, white glaze:
Diameter at base ..... 6"
Height ..... 4"
Surface distance from wire to pin..... 11¼"
Shortest breaking distance .... 6¼"

When dry and clean, broke down at .....74,700 volts.
During dry-snow storm, broke down at.....70,200 "
During moderate rain storm, broke down at ....70,400 "
When covered with wet snow, broke down at ...42,800 "
When dry, stood for ½ hour .....52,500 "

No. 7—Glass:
Diameter at base ..... 7"
Height ..... 6"
Surface distance from wire to pin..... 15½"
Shortest breaking distance..... 7⅞"

When dry and clean, broke down at .....74,700 volts
During dry-snow storm, broke down at.....73,800 "
During moderate rain storm,broke down at .....52,800 "
When covered with wet snow, broke down at ...51,100 "
When dry, stood for ½ hour .....55,000 "

No.8—Glass:
Diameter at base ..... 7½"
Height ..... 5½"
Surface distance from wire to pin..... 12"
Shortest breaking distance.. ..... 7⅝"

When dry and clean, stood .....91,800 volts.
During dry-snow storm, broke down at.....87,300 "
During moderate rain storm, broke down at ....62,700 "
When covered with wet snow, broke down at ...58,800 "
When dry, stood for ½ hour .....63,000 "

FIG. 3.

After the insulators had been up for some months and were well coated with dirt and soot they were given a time test on a dry day. The time test was made by applying ¾ of the maximum test voltage for ½ hour. The figures are given under the last heading in each set of tests. All the insulators stood this test without any evidence of trouble, except a considerable static discharge over some of those with the thinner sections.

I think that the burning of pins is caused in many cases by the static discharges which appear at the wire and at the pin. If the material can be made thick enough, so that these discharges will not appear, the burning of the pins will probably be decreased to a very considerable extent. I think the final solution of the pin-burning question would be to discard the wooden pin altogether and substitute a metal pin properly cushioned to take undue local strains off the insulator itself.

Mr. Grace called attention to the trouble which the telephone ompanies have had from electrostatic effects. As fast as one difficulty has been overcome another is encountered, to overcome which new methods must be devised.

The system of transposing wires in order to overcome the induc-

tive effects of one circuit upon another was devised by the telephone engineers and first used on the long-distance circuit between New York and Philadelphia.

The necessity of keeping telephone circuits in absolute balance was mentioned and a number of instances were given where an extremely small amount of unbalancing was sufficient to produce serious disturbances.

Mr. Grace said that Mr. Lincoln's paper treated only of telephone circuits upon the same poles with the power circuit, whereas in commercial telephone service there were many thousands of circuits and it is manifestly impossible to insulate them to so high a degree as where there is but a single telephone circuit. He thought that representatives from the telegraph, telephone, and power-transmission companies should convene and devise suitable means for crossing the different lines where it is necessary.

Mr. Frankenfield commented on the effect of grounding the neutral point of a transmission system. He also commented on the burning of insulator pins.

Mr. Bedell recounted his experiences while testing insulators. His general conclusions were that the question of dielectric strength of glass and porcelain had been satisfactorily settled, as insulators almost never broke through the dielectric but over the surface.

MR. LINCOLN:—One interesting statement made by Mr. Grace was that the arc circuits of the " tub system," so-called, is one of the hardest things the telephone people have to contend with. This sustains one of the arguments made in my discussion—that the static induction gives more trouble than the electromagnetic. The conductor in such an arc system is apt to be at a considerable difference of potential from the earth, and usually in the arc circuit the equal and opposite potential is not present to neutralize its effect as is the case with a statically balanced transmission line. I should imagine the arc circuit would be harder to contend with, though its potential is not so high as that of the usual accompanying transmission line. I should like to have Mr. Grace explain what he calls a retardation coil.

MR. GRACE:—It is an electric choke-coil and we speak of it as a retardation coil.

MR. ETHERIDGE:—I wish to refer particularly to the necessity of studying every detail of a transmission line, with the view of applying the latest and best possible forms of construction to insure the stability of the medium between the step-up and the distant step-down transformer.

Estimates are carefully prepared and the best engineering skill applied to the erection of central plants and substations, but the transmission line, which is subjected to the worst possible mechanical and electrical strains and conditions, is, generally speaking, the least considered and provided for.

The building of a transmission line is purely a mechanical problem, and must receive as much care and skill as the remainder of the system, if stability of action—which is the keynote of engineering success—is to characterize its operation.

The average transmission line suffers from comparison with the modern power house and substation equipment, and as the system is strongest only at its weakest point greater care and skill must be applied to that part of the system which is found outside the buildings, where the most adverse mechanical and electrical conditions are encountered.

Our worst experience in the operation of transmission lines has been due to mechanical weakness of some of the details of the line; particularly wooden pins and faulty mechanical design of some of the insulators. The angles and guys have also given us trouble on account of their inadequacy for the heavy strains put upon them. I can safely say that electrical troubles of our line have been entirely absent. To overcome the mechanical troubles of pins and insulators, we were compelled to design and adopt a form of pin and insulator a sample of which you will find on exhibition here this evening, and in which the greatest mechanical strength and other features are embodied.

Having solved the question of weak pins and insulators, we next turned our attention to the angles of our line and to proper guying with the result of developing a rigid and successful form of construction. In these angles we have adopted poles of 13″ and 14″ tops, 4″ × 5″ double oak cross-arms with $\frac{3}{4}$″ ring bolts and washers. The braces are $\frac{3}{8}$″ × $1\frac{1}{2}$″ and 30″ long, bolted with $\frac{1}{2}$″ × $\frac{5}{8}$″ bolts and washers in cross-arms and through the poles, respectively. The cross-arms are bolted together with $\frac{5}{8}$″ bolts and washers with the usual making-up piece between them. The pin-holes in the cross-arms are $1\frac{1}{2}$″ diameter, thereby maintaining the strength of the arm. Great care is also exercised in placing the arms diagonally across the angle so as equally to distribute the strain on each pin and insulator.

The " wet-rot " of our poles at the butt received our next attention, as it became evident to us that in seven to ten years our entire pole line would have to be rebuilt; a feat fraught with great danger, expense, and interruption in our service, if it did not threaten absolute shut-down.

I developed and adopted a remedy against this " wet-rot " of our poles. This consisted in cementing about one-third of the pole flush to and extending about 3″ above the ground line, and then placing a fillet of pitch, asphaltum, or some such moisture-proof material to a depth of about 8″ between the pole and cement of the ground-line, so as to separate or seal the pole from contact with the moisture in the earth at the ground-line. This very effectually prevents " wet-rot " of wooden poles and oxidation of steel poles at the ground-line. The additional expense of preparing and treating our poles in this manner is very trifling compared with the great expense of replacing them.

Mr. Scott has well said that " development of detail in electrical machinery has made possible very reliable forms of apparatus," and the same reasoning and skill must be applied to our transmission line before the ideal electrical transmission will be attained.

At the request of Mr. Lincoln I will explain the features of the pin and insulator which it was my pleasure to develop. It consists of a malleable iron tube $1\frac{7}{16}$" outside diameter and $1\frac{1}{8}$" inside diameter. On the outside of this tube-pin is cast a shoulder on which it rests when placed in the cross-arm. To lock this tube-pin to the cross-arm a flat high-carbon steel spring—on each end of which if formed a gib—is driven through the pin until the bottom end springs out over the bottom end of the pin and cross-arm.

The insulator, which has a plain hole to receive the pin, and a recess at the bottom of the hole to receive the top gib of the spring, is then forced down over the pin until the top gib springs out into the recess in the insulator. This combination very securely locks the insulator to the pin and the pin to the cross-arm; to unlock, place a screw-driver between the lower gib and the pin, force the gib back and drive the spring out through the pin again.

The features of this form of pin and insulator are:

(1) Simplicity and durability.

(2) The presenting of a plain surface, so as equally to distribute the wire pressure between the contact or bearing surface of the pin and insulator.

(3) Secure locking to the cross-arm and ease of removal therefrom.

(4) Freedom of insulator to turn in either direction on pin and act as a sheave to the wire when used in angles.

(5) Looseness of the insulator on the pin, avoiding the breaking of insulators from expansion or contraction.

(6) Locking the insulator to the pin and cross-arm, yet preserving looseness and freedom on the pin.

(7) The placing of the wire groove in insulator so as to relieve the insulator from any wire leverage and any stress other than one tending to crush the glass or porcelain, etc.

Our telephone system is erected on the same poles and is bracketed about 5 feet below the lower cross-arm. These lines are absolutely quiet, the electromagnetic and electrostatic influence being overcome by using twisted pairs of wires.

(For illustrations of pins described by Mr. Etheridge, see New York Discussion, March 27th, 1903)

MR. THOMAS:—As Mr. Etheridge has said, the greatest practical difficulty in the operation of high-tension transmission lines arises from mechanical defects rather than electrical ones. Broken pins, broken cross-arms, broken insulators and injuries to the line from external causes vastly outnumber the electrical failures. As is easily seen, the pin is the weakest mechanical link

of the system and when of wood of good insulating quality it is liable to be weak. I wish to call your attention to a plant installing at Mexico, which marks an improvement in pole-line construction from a mechanical point of view. Five hundred foot spans are used, which is approximately five times the length of span usually employed elsewhere, and instead of the usual wooden poles there are built-up steel towers. The cross-arms and pins, I understand, are of steel, the insulators of porcelain. This construction if well designed assures excellent mechanical qualities, and should be watched with great interest. On account of the small number of poles a much larger pin can be economically used for each one.

Ground wires, such as Mr. Lincoln has recommended for protecting the telephone circuit on a transmission line, might be used on telephone trunk lines, parallelling transmission lines, close to the telephone line but between it and the power line. It is probable that a very great reduction of the static induction from the high-tension would be obtained by the use of even a few grounded wires as a screen. I make this suggestion to Mr. Grace.

The question of lightning arresters for telephones, and the fact that they are ordinarily adjusted to discharge at about 300 volts, suggests the mention of a point in the operation on the telephone lines and power circuits by which in some cases the service has been very much improved. In a good many power transmission systems where the standard telephone arrester is used on the telephone circuit, it has been found that there is at almost all times a sufficient unbalance of the high-tension voltage so that a frequent discharge to ground occurs over these arresters, the result being a leaky line and more or less continuous rattle of the telephone. The construction of an air gap in place of the lightning arrester very much reduces the number of such discharges to ground and entirely prevents the high resistance leak which usually occurs in a telephone arrester. The result is a great improvement in the speech.

Some of the telphone engineers here have referred to the problem of making satisfactory cross-overs between two lines. From their point of view the transmission line is a telephone line. The problem is broader, however, and should include the crossing of two high-tension lines. The National Board of Fire Underwriters has recently adopted recommendations as to methods of such cross-overs. They suggest three methods, but preference is expressed for crossing by means of a pole common to the two lines. This pole should, of course, have extra strength and extra height, the highest tension line being carried at the top. Extra long cross-arms are used and the difference in the height of the poles of the upper and lower lines will ordinarily prevent anything which falls from the upper wire to the ground from touching the lower wires. To prevent a wire breaking at the farther end of one of the adjacent spans of the higher line from falling against the lower line, a guard wire mounted on the line, prefer-

ably insulated, should be installed outside of the extreme wire of the lower line.

A wooden pin is burned by leakage current because either its resistance is too high to transmit the current without excessive heating, or because its insulation is too low to prevent the leakage. In most cases either a better or a worse pin would not be injured. A comparatively few per cent. improvement of the pin would in many cases be sufficient to prevent destructive heating. Therefore, the method used by Mr. Gerry for protecting the pin which has been put in first-class condition, from moisture and dirt, by means of a sleeve, is an excellent one, since it will certainly give a considerable protection to the pin and render it oftentimes safe where an unprotected pin will conduct enough to become charred. Mr. Gerry's freedom from trouble from burned pin referred to by Mr. Skinner is probably due to the fact that his pins are protected by glass sleeves, but also it must be admitted that his line is yet young and the climatic conditions are not severe. San Francisco is probably one of the hardest places in the country on pins and I think no wooden pins would be able to stand indefinitely there without burning.

Since the difficulty of operating a telephone line on an unbalanced high-tension power line results from the tendency for a high-potential to ground—equally on both telephone wires provided the telephone line be transposed—it may be possible to solve the difficulty by insulating the telephone line highly and allowing it to assume its neutral potential, and transmitting the speech through a raising and lowering transformer at either end. The low-tension windings of these transformers may then be grounded, and with good insulation between the high and low-tension windings the operation may be made very secure.

I would like to ask Mr. Grace whether it is feasible to use such a transformer for transmitting telephonic speech.

The same sort of result might be attained by the use of condensers, two in series with middle grounded, connected between the wires of the insulated telephone line, the telephone receiver or transmitter being connected between the ground plates of the two condensers. For this purpose it would probably be necessary to use a double winding, either on telephone-spool or choke-coil, so that the charging current to the condensers would have its effect on the telephone circuit neutralized.

MR. GRACE:—The use of the transformer, as suggested by Mr. Thomas, is feasible.

MR. PECK:—In his paper on the testing of insulators, Mr. Blackwell says: "There should be but one transformer used to step up to the highest potential required and its reactance should be as low as possible. A number of transformers in series is particularly bad, as it gives poor regulation and leads to great uncertainty as to the actual potential to which an insulator is being subjected."

In the discussion at New York, Mr. Mershon called attention to

the advantages obtained by the use of a number of transformers in series for obtaining a high voltage, saying that it was possible to obtain such a series having a good regulation; and great point in its favor was that in case of accident to one transformer of a series, the remaining transformers could be used to deliver a some what lower potential.

There is an idea more or less generally prevalent that it is possible to obtain without danger a high voltage by connecting in series a number of transformers wound and insulated for a low voltage, as long as cases are insulated from each other and from the ground. Fig. 1 shows such an arrangement, where three 10,000 volt transformers are connected with high-tension winding in series for giving 30,000 volts.

It will be at once seen that there is a strain of 30,000 volts at the two points (A) and (B). The normal strain for one transformer is 10,000 volts, so that the outside transformers of the series are subjected to three times normal voltage strain be-

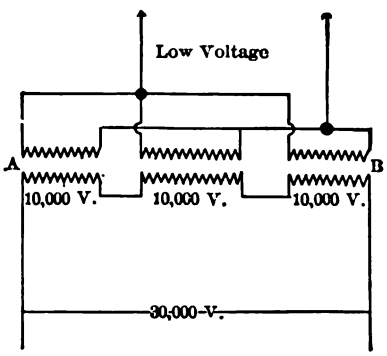


Fig. 1.

tween primary and secondary windings. If there were ten 10,000 volt transformers connected in series for 100,000 volts, the strain across the outer transformers of the series would be 100,000 volts, ten times normal.

In the operation of a number of transformers in series for obtaining a high voltage, there are much more severe internal strains introduced than where the transformers are used for a low voltage. This strain occurs between turns and layers and comes principally on the outside coils of the outside transformers of the series. In designing transformers for connecting in series it is therefore necessary to insulate each transformer not only between high-tension and low-tension windings, but between turns and layers of each winding, in the same manner that would be required were the transformers to furnish alone the full voltage of the series.

On account of the large amount of insulating material demanded between high-tension and low-tension windings, it is

extremely difficult to make these transformers with good regulation on inductive loads.

The cost of small transformers for very high-voltage work is, within certain limits, almost independent of the capacity; so the difference in cost between one transformer of the series and a single transformer wound for the total capacity would be very small.

It is true that the outer transformers of a series may be more heavily insulated than the others, making a reduction in cost on the inside transformers, but this affects the interchangeability of the transformers and the extra cost of manufacturing transformers which differ slightly from each other will probably more than counterbalance the saving in insulation.

The question of a spare unit is undoubtedly of importance, but I believe that in general it will be cheaper to purchase two transformers, each wound for the full testing voltage, than to buy a large number of transformers which are to be connected in series for giving the desired voltage. Where two transformers, each wound for the full testing voltage, are purchased, one will of course be held as a spare and may be used as a voltmeter transformer for obtaining the exact voltage applied to the apparatus on test.

When a number of transformers are in series, the voltage measured across the high-tension winding of one transformer will not be an accurate indication of the total voltage on the series.

Mr. Rice called attention to the importance of uninterrupted service and to time tests on insulators. He predicted that the highest transmission voltage would very soon be generated directly by the dynamos, without the use of raising transformers. He also thought that the shoulder on the proposed pin was too small as the side strain would cause the shoulder to cut into the cross-arm, thus enlarging the hole so that the pin would finally pull out.

MR. SCOTT:—I recall my first experiments on the relation between the telephone and a high voltage. In the laboratory a telephone was connected in circuit between a high-tension terminal and a short length of wire. It gave a vigorous sound which was attributed to the flow of current to the wire acting as a condenser. The wire was disconnected and the telephone still responded. The wire was then disconnected from the telephone circuit and was connected to the insulated magnet. The telephone still responded.

Some measurements upon the potential generated on an insulated wire not far from a high-tension circuit which were made by Mr. Tingley, who is here this evening, are reported in a paper on High-Voltage Transmission presented before the INSTITUTE by me in 1898. These experiments show that a single insulated wire not far from a high-tension wire may have a potential sufficient to cause a spark to jump over a considerable gap to the earth.

I had an opportunity a few years ago to inspect the burning of pins and cross-arms on a 10,000 volt transmission line on the Pacific Coast, which ran for some distance close to the shore. Large holes were burned in some of the cross-arms and poles. The burning was particularly apt to occur at the ends of the iron braces between the pole and the cross-arm. There was little doubt but that particles of sea water as " fog " were carried by the wind and deposited salt upon the poles and cross-arms. I understand that this difficulty has been avoided by placing wooden frames over the insulators on the ocean side.

Mr. I. Sternefeld of Mexico has called my attention to the deterioration of copper wire due to the salt air from the ocean He says that he has found a satisfactory remedy in an insulated coating consisting simply of cotton dipped in a solution of minium and linseed oil.

It is notable that *megohms*, which used to be considered of prime importance in the testing of electrical apparatus, has not been mentioned in the discussion this evening. The problem in line construction is primarily to prevent disruptive and disastrous breakdown. It is not the *ohms* but the *volts* which are of first importance.

The collection of insulators before us this evening, containing some early forms as well as recent ones, small insulators as well as big ones, indicates the evolution which has taken place in insulator construction, both in materials and form during the last ten years.

The insulator problem, as presented in the discussion this evening, is at the present time primarily a mechanical problem. Electrically, it is partly one of materials and partly one of geometry. There is an intimate relation between geometry and voltage in insulator design. There is also the commercial problem.

High-tension tests upon apparatus, particularly transformers, is an important matter. The conditions prevailing at high voltages are to my mind different from those at lower voltages. Low-voltage apparatus may probably be tested at several times its operating pressure. The margin between the normal pressure and the test will be but a few thousand volts. If, however, transformers for 40,000 or 50,000 volts be tested at double pressure the margin is also 40,000 or 50,000 volts. The purpose of making a test of this kind is to determine first whether the design is satisfactory in giving sufficient surface distance and the like, and second to detect flaws in material or in construction. A momentary or short test is in general sufficient to determine these points. The prolonged test may have a deleterious effect upon the insulating materials by weakening them. The test may result in a breakdown due to conditions entirely abnormal to service. On the other hand, although there may be no breakdown the materials may be left in a condition weaker than they would have been if the test had not been prolonged.

MR. BUDD FRANKENFIELD:—Speaking of the dependence of transmission systems on the telephone in time of emergency, recalls an incident that came under my observation on the coast. It belongs in the category with the somewhat disastrous accidents that sometimes occur when too great reliance is placed on automatic devices.

A fire occurred in a city that received power from a long-distance transmission system. The fire caused havoc in the secondary network, and the substation attendant pulled all his switches in the emergency, without first notifying the power house. At the power house the governors happened to be off duty and the impulse wheels took on speed. Instead of taking recourse to the "Armstrong system" and shutting down the plant as he might have done, the power station attendant ran to his telephone booth to call up the substation.

He never got into communication; for there was a crash which brought him out of the booth to gaze in open-eyed wonder at the roof above—the fly wheel had gone soaring heavenward and it left a great hole in its wake. Here is an instance where it had become so natural to use the telephone in every emergency that, what is ordinarily a blessing, proved a source of danger. The moral is to use "horse sense" even when surrounded by modern conveniences.

In regard to the suggestion that the ground be brought near the telephone line by means of an earthed conductor placed in proximity, I would like to recall the fact that grounding the neutral of a Y. connected transformer system has this effect, as stated in the paper, that the telephone line tends to assume the potential of the neutral point of the transmission system; and the grounding of this point will virtually bring the telephone line to the potential of the earth. It seems to me a method worthy of careful consideration.

It has been suggested that by using an iron insulator pin burning would be avoided because of the low resistance of the pin; and it has been urged in opposition, that the wooden pin has some give to it and is less likely to break insulators. Why not combine all the good qualities in one pin, a wooden pin with a metallic coating? Cover it with foil, paint it with a metallic paint, electroplate it if need be—do anything to make it a good conductor. A study of the Redlands type of pin, which is said to have shown deterioration only at the wooden thread and which is said to have caused no burning of cross-arms, is an indication of the result to be expected with a metal-coated pin—no burning at all.

A paper read at a meeting of the American Institute of Electrical Engineers, and the American Electrochemical Society, New York, April 17, 1903.

RADIOACTIVE SUBSTANCES.

INTRODUCTION BY PRESIDENT SCOTT.

We are pleased to have with us as guests this evening the members of the American Electrochemical Society. This Society by its name indicates the intimate connection between two branches of science and of industry. Electricity and chemistry in many of their aspects may have little in common; but the mystery of electricity and the secret of chemical affinity are not far apart. There is an overlapping field in which there is a new science, a new industry and a new society.

The secrets of nature are discovered as individual and usually as isolated facts. These are classified and their generalization results in laws—the laws of nature. This is the field of the scientist. These laws are then applied to direct the forces or mould the materials of nature to accomplish useful purposes. This is the domain of the inventor and the engineer. Scientific and engineering advancement are closely related and their proper equilibrium is essential to advancing civilization. If there be too great generalization from inadequate data or inaccurately observed phenomena, or, on the other hand, if there be meagre ability to apply properly deduced laws to new conditions, the results are of little moment. The notable scientific advancement of the past century has been based upon the fact that men have sought to observe phenomena and obtain definite data before drawing their conclusions instead of speculating upon vague or hypothetical conditions. Along with this development has come also facility in inventing and in applying and utilizing the deductions of science To illustrate: In the early part of the last

century men were seeking to discover facts to demonstrate the suggested interrelation between electricity and magnetism. Faraday and Henry independently and almost simultaneously determined by experiment that electricity can be produced by magnetism. These facts were amplified by other facts and led to generalizations and laws, and later to dynamos and motors. The dynamo and motor had a very slow development, as it seems to us now. Years were required before the machines began to have an extended application. Later on, developments have been rapid and extensions have been marvelous.

Compare this development reaching over the span of a lifetime with a recent development—that following the announcement of the discovery of the X-ray by Prof. Roentgen. Immediately in laboratories all over the world elaborate experiments and investigations were begun, apparatus was forthcoming for practical use and within a twelvemonth the X-ray was an important adjunct in many a hospital.

There has been a change in the method of doing things, in the method of scientific observation and of scientific generalization on the one hand, and in the ability of the inventor and the engineer to develope and utilize the new material which is put at their disposal. We must add to this as a factor in modern development the attitude of the public at large. The scientific observer and the inventor are no longer wizards to be shunned or executed. Science and engineering have done so much in the past that there has come to be a wonderful faith in the future.

Sometimes, it is true, the zeal of the promoter has overweighed the judgment of scientist and engineer, and disappointment has followed the exploitation of schemes which are fundamentally impossible.

It is difficult to foresee the future. Again and again experiments and facts which seem of most trivial consequence have led to far-reaching results in fields least expected.

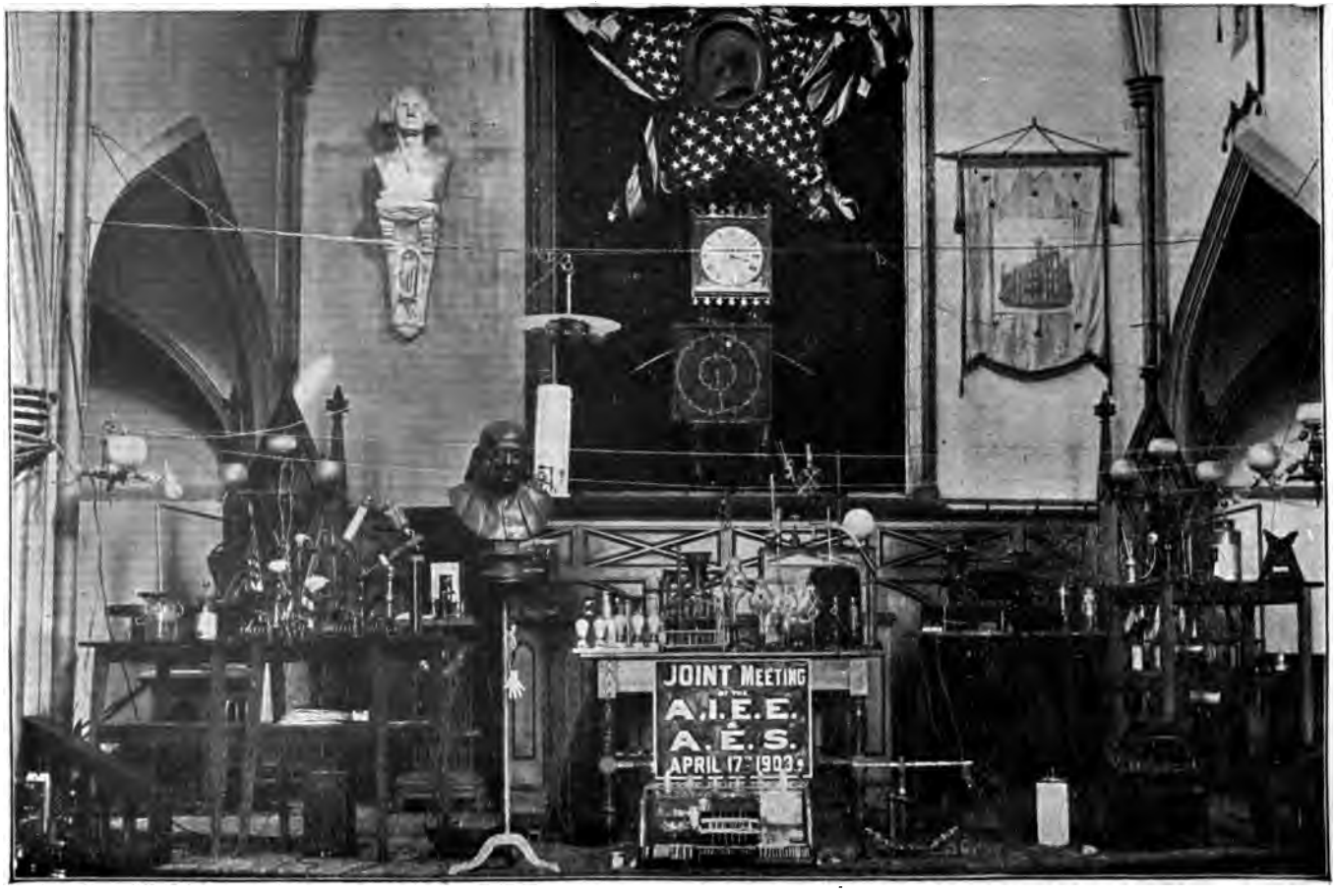
A simple experiment, the discovery for example of the relation between electricity and magnetism, is the basis of new systems, for the instantaneous transmission of intelligence and the efficient transmission of power.

The discovery of a new property is the opening of a new field of possibility to the scientist, the inventor and the engineer. Hence the value of research. The advanced investigator and the research laboratory are not to be ridiculed if they do not produce full-fledged new methods and new processes superior to

those which have undergone years of development. Fortunate are they if they discover new properties of matter or new relations and combinations which may be the source from which new developments may spring.

On the one hand, we marvel at the advance which has been made in science, invention and engineering. On the other hand, we find that in every direction we have only entered upon the fields of nature which lie before us promising and unexplored. In the production of light and mechanical energy, for example, we are wonderfully in advance of our forefathers, but our present methods are crude and inefficient compared with what we know to be theoretically possible in the transformation of energy, if we had but the means.

It is therefore with a peculiar interest that we direct our attention to an unfamiliar subject; that we learn the wonderful properties of a rare element; that we direct our thoughts to a new field laden with great possibilities.



Stage Setting in the Chapel of the "College of the City of New York" at the time of Mr. William J. Hammer's Lecture before the American Institute of Electrical Engineers and the American Electrochemical Society.

A Lecture delivered at a meeting of the American Institute of Electrical Engineers and the American Electrochemical Society, New York, April 17th, 1903.

RADIUM AND OTHER RADIOACTIVE SUBSTANCES WITH A CONSIDERATION OF PHOSPHORESCENT AND FLUORESCENT SUBSTANCES. THE PROPERTIES AND APPLICATIONS OF SELENIUM AND THE TREATMENT OF DISEASE BY THE ULTRA VIOLET LIGHT.

BY WILLIAM J. HAMMER.

The author of this paper has endeavored to exemplify certain fundamental principles connected with the phenomena upon which he has treated; and in considering these subjects, all of which may be said to be on the borderland of science, to bring out by means of experiments, lantern slides and illustrations which accompany the paper, the practical and commercial side. He entertains the hope that the matter herewith submitted will prove of interest to the members of the societies before whom he has the honor of appearing, and may serve in some slight degree to stimulate investigations in these most promising fields.

FLUORESCENCE AND PHOSPHORESCENCE.

Sir George Stokes has given the name of " Fluorescence " to the phenomena which certain substances present in altering the very short waves of ultra-violet light, which are invisible, and transforming them into waves of longer length so that they become visible to our eyes.

In electrical parlance a fluerescent substance might be termed a step-down transformer or perhaps more correctly a frequency changer for light waves. Stokes, as a result of his investigations, framed this law, " When the refrangibility of light is changed by fluorescence it is always lowered and never raised "—in other words, the waves emitted during fluorescence are always longer than those which are absorbed, thus causing fluorescence. There are, in fact, cases where the frequency of

the radiations is increased; but where there is such an exception to Stokes' law some sort of chemical reaction occurs.

The lowering of the frequency of certain ultra-violet radiations, so as to render them visible, was known to Brewster in 1833 and Herschel in 1848, the former terming it internal and the latter surface dispersion; but it was first explained and the name given to it by Stokes in 1852, after a form of fluorspar.

In the case of fluorescence, the emission of the light lasts only so long as the substance is stimulated by the incident beam; but in the case of the phosphorescence, the emission of light continues or persists after the stimulation has ceased, or the original source has been removed. The word phosphorescence is from the Greek " phösphoros," meaning light bearer.

Prof. E. Wiedemann has suggested the name " luminescence," to cover fluorescence, phosphorescence and phenomena of that character possessed by many substances whose light emissions are unaccompanied by flame or by the temperature of ordinary light waves; but this term can hardly be made to cover the Becqueral rays emitting from radioactive substances.

I have here to-night a collection of tubes containing fluorescent liquids, such as petroleum, quinine, Magdala red, eosine, uranine, saffronine, paviine, æsculine, amidophthalic acid, fluorescine, rhodamin, etc., all of which show most beautiful changes in color when viewed by direct and transmitted light.

I also have some of the fluorescent hydrocarbon " thalleen," prepared by the late Prof. Henry Morton, and some of those most beautiful fluorescent substances, resorcorufin and resorcin blue, for which I am indebted to Dr. Geyer of Steven's Institute. Fluorescent substances are particularly beautiful in the ultra-violet light; for instance: The yellow fluorescene becomes a most beautiful green; the orange colored eosine becomes gamboge; the crimson color of Magdala red a bright scarlet; the straw colored æsculine becomes a pale blue; the transparent and colorless quinine gives its characteristic blue surface tint; the paraffin oil a beautiful blue; and the various other substances giving a beautiful surface color quite different from that of the interior of the solution.

Small pieces of horse-chestnut bark or bark of the ash tree placed in a dilute ammoniacal solution produce a most beautiful fluorescent effect, as the dyeing material descends slowly through the liquid.

Flowers painted with these fluorescent substances on card-

board produce a most beautiful effect when light screened by dark blue or violet glass is thrown upon them.

Sodium vapor fluoresces brilliantly in sunlight.

I also have here samples of tungstate of calcium, platino-barium cyanide, sulphide of zinc, and similar preparations which have been extensively used in the fluorescent screens for X-ray work.

Here is a specimen of Willemite which when exposed to the ultra-violet light produced by the bright snappy condenser spark between these iron electrodes shows a magnificent fluorescence.

Here is a card with words written with a solution of platino-barium cyanide which fluoresces beautifully when exposed to the ultra-violet light of the iron arc, especially when shielded by the accompanying colored glass plates.

I have also one of Prof. R. W. Wood's interesting ultra-violet screens, consisting of four plates of cobalt glass between which are gelatine films containing nitroso-dimethyl-analine with copper oxide, which screen when employed in front of the arc lamp renders beautifully fluorescent a lump of uranium nitrate held in the focus of the invisible rays.

Through the courtesy of Dr. Von Recklinghausen, I am enabled to show you a Cooper-Hewitt tube which is enclosed in a screen soaked in rhodamin, the best substance which thus far has been found which is fluorescent in the light of the mercury arc.

It is well known that many bodies become red hot at a temperature of between four and five hundred degrees Centigrade, and to make them white hot a temperature of between eight hundred and a thousand degrees is necessary; but there are many substances which are phosphorescent and which possess the property of giving off considerable light without sensible heat.

I have here some samples of two phosphorescent substances which have been known for many years—one of them a sulphide of barium or Bolonese phosphorus, and the other a sulphide of calcium or Canton's phosphorus. The former was discovered in 1602 by Casciarlo, a shoemaker in the city of Bologna who prepared it by the partial calcination of a certain powdered heavy spar mixed with a little flour meal, which he roasted in the furnace; and found afterwards that when exposed to sunlight it would shine in the dark. This preparation was succeeded by the discovery of John Canton, who calcined oyster shells with charcoal and meal in a closed crucible, thus producing a brilliant phosphorescent substance called after his name.

Phosphorescence by insolation—or exposure to sunlight—has been extensively investigated by Prof. A. E. Becquerel and Dr. John W. Draper.

Practically all substances in nature are phosphorescent, and although some of them remain phosphorescent for only one ten-thousandth of a second, others retain their phosphorescence for hours.

One may expose sulphide of calcium to sunlight, and after placing it in a dark room for six weeks it will still affect a photograph plate.

Phosphorescence may be stimulated in many ways—by combustion, pounding, rending, friction, by the vibrations from sources of heat, light or electricity; and these various phosphorescent substances are very susceptible to temperature changes.

Various substances also phosphoresce while undergoing crystallization.

I have here a large sheet of cardboard which has been prepared for me by Messrs. Devoe & Company, which is covered with seven coats of Balmain's Luminous Paint or poly-sulphide of calcium, with perhaps a trace of bismuth and mixed with aerated varnish; and it has been put through hot calender rollers. You will note that this phosphoresces most beautifully when excited by burning this piece of magnesium wire before it, or by focusing the arc light upon it. This phosphorescence soon dies out, however; but upon placing my hand against the sheet, the heat of my hand has caused the card to brilliantly phosphoresce. A cold object placed against the cardboard will very much lessen the phosphorescence at that point.

When I place this bust of Franklin between the arc light and the phosphorescent cardboard, you will note I can thus produce a fine silhouette of that distinguished philosopher.

I have prepared for your consideration a number of objects coated with phosphorescent substances. When I burn this piece of magnesium wire in front of this card, or hold it before the arc light, you will note the initials of the A. I. E. E. and the A. E. S., the two societies before which I have the honor of appearing to-night, shine out brightly. I also have a number of incandescent lamp bulbs, coated internally and externally with phosphorescent substances, which you will note give considerable light when stimulated by the burning magnesium; or by turning on the electricity supplying certain of the lamps.

I remember nearly twenty years ago having cut out tiny stars

from cardboard and painted them with luminous paint, and arranged them on the ceiling of my bed room to represent certain of the principal constellations in the heavens. These stars would absorb the light during the day time, and at night would represent an appearance as though the roof had been removed and one was looking at the stars in the sky.

I have here a philosophical toy which I made years ago, with which I can show the varying phases of the moon. I have taken a 25 cent globe, and painted half of it with black Japan, as representing the dark side of the moon which is never seen, the other half I have painted with a number of coats of luminous paint; and by exciting the phosphorescence of this half by the burning magnesium, you will see that by slowly turning the globe around, a perfect representation of the varying phases of the moon occurs.

I hold in my hand here a long tube coated inside with sulphide of calcium, which makes a beautiful wand, which an orchestra leader might use in a dark scene. I remember years ago fixing up a vacuum tube and coil for use as a baton in the dark scene in Gilbert & Sullivan's Opera of Ruddigore, and fearing lest the complaisant leader be some day knocked off his stool by the 8-inch coil.

Here are a couple of postal cards which I secured in Europe showing the Blue Grotto at Capri. They are printed with phosphorescent paints; and on exposing them to the light, you will see they are exceedingly pretty.

Prof. Dewar has shown that egg shells, feathers, ivory and paper become brilliantly phosphorescent if they are cooled to about 200 degrees below zero by use of liquid air, and then exposed to light. Many bodies seem to possess this power of absorbing energy at low temperatures and giving off light at higher temperatures. In fact, Dewar has observed that at a temperature approximately that of the boiling point of oxygen (184° C) all bodies, even living tissues, become phosphorescent.

I have here a collection of forty or more glass tubes containing various phosphorescent substances which, when I burn this magnesium before them, you will note become brilliantly phosphorescent, showing red, yellow, green, blue, and in fact, all the colors of the spectrum. The sulphides of calcium, barium, strontium, zinc, etc., largely enter into their composition. I also have here some fine particles of fluorspar. which, when scattered on this hot plate, glisten like fire flies.

A similar effect may be produced by quinia or its sulphate which when spread on a sheet of paper and laid on a hot metal plate in a dark room, shows a remarkable phosphorescence which develops at the edges and spreads to the centre.

Boracic acid fused and allowed to cool breaks into small pieces, and along the cracks phosphorescent light appears. Potassium sulphide fused with cream of tartar shows the same phenomenon.

Phosphorescent ether may be prepared by digesting phosphorus in ether for some days in a tightly corked bottle, and when a lump of sugar is dipped into this and dropped into a glass of water, the surface appears quite luminous.

The stream of particles, so thoroughly investigated by Prof. Crookes, was given the name of " Cathode rays " by the Germans, as a protest against Crookes' theory of molecular streams propounded by him at the British Association meeting of 1879; Lord Kelvin has told us that the smallest particle which can be observed by the most powerful microscope contains 18 to 20 million atoms, and although until recently the smallest particle we could conceive of was the atom of hydrogen, this being the lightest of gases, Prof. J. J. Thomson has now shown us that these atoms may constitute a thousand fragments, or as he calls them, " corpuscles," and Crookes showed us, and Villard of Paris recently demonstrated conclusively that the Cathode rays consist of a stream of these hydrogen corpuscles negatively charged and moving at a speed approximating 70,000 miles per second; and as illustrating the complexity of an atom, I am reminded by Prof. Hallock that the late Prof. Henry Rowland once said that a Steinway grand piano was a comparatively simple piece of mechanism compared with an iron atom.

Prof. Crookes has shown many notable experiments in which substances have been caused to phosphoresce inside of the Crookes' tube by the molecular bombardment of " Cathode rays ", and I have here some fine Crookes' tubes containing red and white coral, rubies, calcite, lava, etc., which you will note phosphoresce finely. (I am indebted to Messrs. Queen & Co. for certain of these.

Prof. Crookes has made a diamond so phosphorescent inside of a Crookes' tube, as to give a full candle power of light. Rubies, emeralds, corals, fluorspar, lime and many other substances similarly phosphoresce in the Crookes' tube.

I have here a Crookes' tube containing calcined sea shells,

which, on connecting to the induction coil, is caused to give off a most brilliant light, and the globe and contents to phosphoresce long after the current is shut off.

Here again I have a tube containing four separately exhausted sections, which are filled with phosphorescent substances, and a tiny tube passing through all of the partitions of the tubes, and being connected with the electrodes at the end. On connecting this to the induction coil a luminous gaseous stream is seen in the tiny tube, and the discharge accompanying it affects powerfully the phosphorescent substances which, you will note, are colored green, yellow, and blue, after the current is shut off.

I have here also a Crookes' " radiometer," the vanes of which are painted with phosphorescent substances, and on connecting the radiometer to the coil the electricity rotates the vanes and causes them to become highly phosphorescent.

At a meeting of the INSTITUTE on January 3, 1902, through the courtesy of Mr. Edison, I was enabled to present some of Mr. Edison's tungstate of calcium lamps which have sometimes been called Edison X-ray lamps. These lamps were Crookes' tubes, the interior walls of which were coated with fused crystals of tungstate of calcium, which were caused to phosphoresce most dazzlingly when they were connected to an induction coil. Through an accident to my large coil, I was unable to show these tubes working as perfectly as I should have liked, and to-night I will show you as an evidence of good faith some of them operating as they should operate, and giving a most powerful light. Incidentally, I am going to show you that this cannot properly be called an X-ray lamp although a form of X-ray tube is employed, as it is not the X-rays outside but the cathode rays inside of the tube which produce the phosphorescence. This tube which I have here and which I have coated with tungstate of calcium and platino-barium-cyanide on the outside, I will now place underneath an ordinary Crookes' tube, that it may be exposed to the X or Roentgen rays; and you will see that while the coated surface fluoresces, as any fluorescent screen will when exposed to Roentgen rays, the moment these rays cease there is absolutely no phosphorescent effect, there being no persistence of the luminescence.

Now, another thing which I think I can show you is that, while cathode rays produce by their action on the interior wall of the glass tube a secondary effect of ether pulsations on the

exterior which are Roentgen or X-rays, I can now produce the converse of this by bombarding the outside of the Edison tube by the Roentgen rays from the Crookes' tube, and you will see then that I have caused cathode rays to be stimulated in the interior of the tube which is merely held near it, causing the tungstate of calcium to become brightly phosphorescent; and you will note that I can deflect the cathode rays with a magnet. I believe this is the first time this conversion of Roentgen rays into cathode rays has been accomplished and is rendered possible by this form of tube.

There are many commercial applications which may be made of this curious property of phosphorescence. Life buoys have been painted that they may be seen when thrown overboard; sheets of cardboard, such as I have shown you, have been used to give light in powder magazines. I have also suggested painting projectiles with luminous paint for use at night; phosphorescent clock and watch dials have been made in large numbers, and it has been suggested to make house numbers, door knobs and escutcheons for key holes of such materials, cover the walls with luminous paper, and even paint the houses with luminous paint.

The taps or keys of incandescent lamp sockets and switches might be made of glass containing phosphorescent material, or the cases painted as I have here done, so that they could readily be seen in the dark; and doubtless certain phosphorescent substances might be used to considerable advantage in connection with various types of vacuum tube lighting and for vacuum tubes used in connection with wireless telegraphy.

I hold in my hand a tiny tube which I secured in Paris, which contains what is perhaps the most brilliant phosphorescent substance that has yet been discovered. It is a special preparation of sulphide of zinc. Here is a second tube containing some of the sulphide of zinc, which also has mixed with it some radium.

A tube of this mixture may be put away in the dark for years, and the radium will act on the zinc, causing it to phosphoresce brilliantly.

Who will say that we shall not some day find a substance which will be so powerfully acted upon by the emanations from radium that it may be used as a source of light?

Here I have a tube which I have made on the suggestion of Prof. Curie, consisting of two bulbs with a stop cock between, in one of which may be placed sulphide of zinc, or similar substances, and in the other radium; and in this manner the radioactivity of various substances may thus be investigated.

A tube containing chloride or bromide of silicon and exhausted to 12 or 15 mm., and sealed, will when rubbed briskly with silk glow in one case a rose color and in the other a greenish yellow.

I hold in my hand here two Geisler tubes, each containing an inner tube with beaded surfaces. In each of the outer tubes is a small amount of quicksilver; and in one tube nitrogen gas, and in the other carbonic acid gas. By shaking these tubes rapidly the friction of the quicksilver against the glass produces electricity, which causes the gas to become luminescent. Various other gases may be thus employed, producing different color effects.

It has been suggested that life buoys could be equipped with a number of mercury tubes, circular or otherwise, and set in different positions, so that the rolling of the buoy in the sea would constantly agitate the mercury and render the tubes luminous.

Here is a tube containing mercurial salts, which changes greatly the color of its phosphorescence by heating the tube in alcohol flame.

In this box I have a large spiral glass tube which is expanded into bulbs at various points throughout its length. This tube, for which I am indebted to my friend Dr. Geyer, contains sulphuric anhydride; and you will note when I connect this to the induction coil and send a discharge of electricity through it that the gas inside of the tube becomes phosphorescent and remains so for a considerable period after the electricity is cut off.

I have here a bottle containing phosphorus and olive oil, which you will see becomes most brilliantly phosphorescent when I withdraw the stopper, and allow the air to enter the bottle. The phosphorescence in this case is due to combustion, or to the oxidation of the liquid. I can also write phosphorescent characters on this ground glass plate wet in hot water with this stick of phorphorus. Other forms of phosphorescence are caused by chemical changes or the slow combustion of decaying vegetable matter or decaying fish.

Occasionally clouds show a phosphorescent light at night; snow is phosphorescent after exposure to sunlight, and no doubt many substances retain during the night the phosphorescent light imparted by the sun's rays during the day.

There are also many insects, such as fire flies and glow worms, and many deep sea fishes which have the properties of producing phosphorescence. Phosphorescence is exhibited among other animals by the infusorian noctiluca, marine radiates, polyps, etc., which are the principal causes of phosphorescence of the sea.

In Fig. 1, is shown an illustration of the " Pyrophorus Noctilucus." This tropical beetle has been most carefully studied by Prof. S. P. Langley and F. W. Very, and the efficiency of the light given off tested by the Langley bolometer; and they have demonstrated that practically all the energy which its phosphorescence represents, appears as light, and the light given off by this insect is the most efficient light known, it being produced at about one four-hundredth part of the cost of the energy which is expended in the candle flame*.

Sir Oliver Lodge says if the secret of the firefly were known, a boy turning a crank could furnish sufficient energy to light an entire electric circuit.

And Prof. Langley says, " There seems to be no reason why we are forbidden to hope that we may yet discover a method (since such a one certainly exists and is in use on the small scale)

FIG. 1.—"Pyrophorus Noctilucus " (life size), the Producer of the Cheapest Form of Light Known.

of obtaining an enormously greater result than we now do from our present means of producing light."

Langley believes the light of these insects is due to chemical action, as it is decreased by nitrogen which checks combustion, and is increased by oxygen which increases combustion, and furthermore, the product is apparently carbon dioxide.

We also may produce phosphorescence by rubbing crystals together, or by friction of other bodies, or by cleavage, such as fracture of lump sugar in the dark.

Among plants, phosphorescence was first recorded by A. Linnæus, whose daughter discovered it in the nasturtium. Phosphor-

* " On the Cheapest Form of Light," by S. P. Langley and F. W. Very, No. 1258 Smithsonian Misc. Coll.

escence or flashes of light are often observed, especially just after sunset, in the common red and yellow marigold, the tuberose, sunflower, poke weed, martagon-lily and the poppy. The root stock of khus-khus grass and the sap of certain tropical vines and subterranean plants, some liverworts, ferns, mosses, fungi and algæ, and the mycellum of fungi in decaying wood phosphoresce. This phosphorescence is said to be due to slow decay and oxidation, either in the mycelia or fructifications of the fungi. Heat and dryness soon dissipate it.

Having considered certain of the phenomena of phosphorescence and fluorescence, I wish now to call your attention to these remarkable substances which have recently been discovered, which give off light the moment they are created, without having to be stimulated by any form of heat, light, electrical or other vibrations, so far as we are at present cognizant of, and these substances are attracting a great deal of attention, and are likely to teach us more about the constitution of matter, and the co-relation of the vital and physical forces, than any substances which have been created since the world began. I refer to "Radium, Polonium, Actinium and Thorium."

Radium and Other Radioactive Substances.

Prof. Henri Becquerel.
From a portrait presented to the author.

To the discovery of M. Henri Becquerel, member of the Institute of France, in 1896, of those remarkable radiations emanating from uranium, the science, if we may so term it, of radioactivity, owes its foundation

Great importance must, however, be attached to the previous investigations into the phenomena produced on the interior and exterior of vacuum tubes of various kinds by such men as Varley, Hittorf, Crookes, Lenard, Roentgen, Hertz, J. J. Thomson, Goldstein, Schmidt, Ebert, Wiechert, Geissler, Kaufmann, Puluj, Perrin, Villard, Wien, Wiedemann Majorana, Birkland, Deslandres, Poincaré, Edison, Tesla, Rowland, Michelson:

E. Thomson, Moore, Rollins, Campbell-Swinton, and others, which investigations had already wrested from Nature so many secrets bearing upon the constitution of matter and paved the way for the Becquerel rays

Two important links in the chain were supplied by the experiments of M. Henry[1] and M. Niewenglowski[2]. The former showed that phosphorescent sulphide of zinc penetrated black paper and affected a photograph plate, similar to Roentgen rays; and the latter in his experiment replaced the usual cover of a loaded photographic plate holder by a thin sheet of aluminum; on top of this he placed four glass squares sprinkled over with sulphide of calcium rendered phosphorescent by exposure to sunlight. A jeweller's glass bell jar was put over each plate, and the whole apparatus was then placed in a dark room for twenty-three hours. On developing the negative, the plate showed an excellent image of the squares of glass and the bell glass covers which had been made through the aluminum, a substance heretofore supposed to be entirely opaque to light, the white line shown bordering the squares of glass (where the plate had not been affected) indicated that the rays had here been bent or refracted in passing through the edge of the glass, demonstrating that he was only dealing with ordinary light rays.

Subsequently, Prof. Becquerel investigated the effect of phosphorescent substances on photographic plates covered with black paper, such as is used for covering X-ray plates; and which while transparent to X-rays is impervious to ordinary light waves (a plate so protected may be left in the sunlight for twenty-four hours); and he exposed various uranium salts to sunlight to try their effect, at times placing an aluminum, copper or glass plate between the paper and the photograph plate or film. On one occasion after he had placed some double sulphate of uranium and potassium on a photographic plate, the weather became stormy, and he placed his plate with the uranium salts upon it in a drawer, where it remained for several days on account of continuance of the cloudy weather. It then occurred to him to develop the plate: and much to his surprise he found a well-defined impression upon the plate, and this caused without any effect of phosphorescence due to exposure to sunlight. This

1. *Comptes Rendus*, Feb. 10, 1896. Vol. cxxii., p. 312.
2. *Ibid*, cxxii., p. 386.

led to his discovery and investigation of the remarkable radiations which have since been known by his name*.

I have here some samples of the first substances employed by Becquerel, consisting of double sulphate of uranium and potassium and double sulphate of uranium and ammonium, for which I am indebted to the courtesy of Dr. C. F. Chandler, of Columbia University.

Peligot in 1840 succeeded in isolating metallic uranium from the chloride. Well known forms of it are also uranium arsenate, uranium carbonate, uranium niobate, uranium phosphate, uranium silicate and uranium sulphate. Uranium was first discovered in 1789 by the German chemist Klaproth, he naming it after the planet " Uranus." I have here various forms of this uranium and also some metallic uranium prepared in the electric furnace by Moissan, which is more powerful than any other form of uranium.

Uranium, although widely distributed, is never found in large amounts, and forms several minerals. The commonest of these is " uraninite," commonly known as " pitchblende," which is a compound oxide containing 81½ per cent. of uranium, 4 per cent. of lead and ½ per cent. of iron with oxygen and water, and sometimes magnesia, manganese or silica.

The pitchblende which contains the largest percentage of radioactive material which has thus far been discovered is the Bohemian pitchblende. It is also found in Saxony in small pockets, and a distinct vein of it has been found in Cornwall England. Prof. Curie informed the writer that he had secured some excellent radioactive pitchblende from the United States (Colorado).

The ore as mined in Cornwall yields 18 per cent. to 20 per cent. of the metal, this being the most important source, and this is usually put on the market in the form of uranium sesqui-oxide, and is largely used for giving porcelains a velvety black when heated in the annealing fire, and to some extent for imparting a greenish yellow fluorescence to glass. It has also been suggested to utilize it on account of its high resistance in connection with incandescent lighting.

Following the original discovery of the Becquerel radiations in 1896, came the discovery in 1898 of " Polonium," by Prof. Pierre Curie and Mme. Sklodowska Curie, who in investigating Becquerel

*Comptes Rendus, Feb. 24, 1896, Vol. cxxii., p. 420.

radiations from uranium found some samples of pitchblende, from which the uranium is extracted, which was much more powerful than any uranium they had found, being four times the radioactivity of metallic uranium. Concluding naturally that the Becquerel radiations were due to some unknown substance in the pitchblende they commenced a most painstaking search for it, and discovered a substance associated with bismuth, which it resembled very much in its chemical characteristics, to which Mme. Curie gave the name " Polonium," after her native land, Poland.

I have here perhaps the only sample in this country at present of metallic polonium, which in color resembles somewhat the particles of nickel. Here also is some sub-nitrate of polonium.

Where substances are referred to as possessing a certain " radioactivity," for instance 300, it means that the radiations are 300 times as powerful as the original radiations emanating from uranium, which were discovered by Becquerel, and which are taken as a standard of comparison.

The two tubes which I have here to-night are of the sub-nitrate and metallic form, and possess a radio-activity of only about 300. The sub-nitrate form is a white powder, and the metallic, as said, resembles in appearance particles of nickel.

Polonium is precipitated by hydrogen sulphide.

Polonium apparently loses its power much more rapidly than radium; and the Curies have not been able to prepare any in which the rays have been deviable, although Giesel has prepared a form possessing both deviable and non-deviable rays. And Elster states that when polonium is placed in a vacuum, the rays may be deviated by a magnet to a greater extent than those of radium.

Polonium passes more rays through aluminum than do the rays from uranium; but Crookes has shown that they do not penetrate glass, as in the cases of radium, and they are readily absorbed by minerals, and readily cut off by thin paper. They are readily absorbed by quartz, fluoride and mica, whereas these substances are freely penetrated by both radium and uranium.

In the same year in which polonium was discovered, those remarkable investigators, M. and Mme. Curie and M. Bemont, succeeded in isolating a second substance found in pitchblende which was associated with barium and possessed many of the chemical and other characteristics of that substance, and to this they gave the name " Radium." Of this we shall treat later.

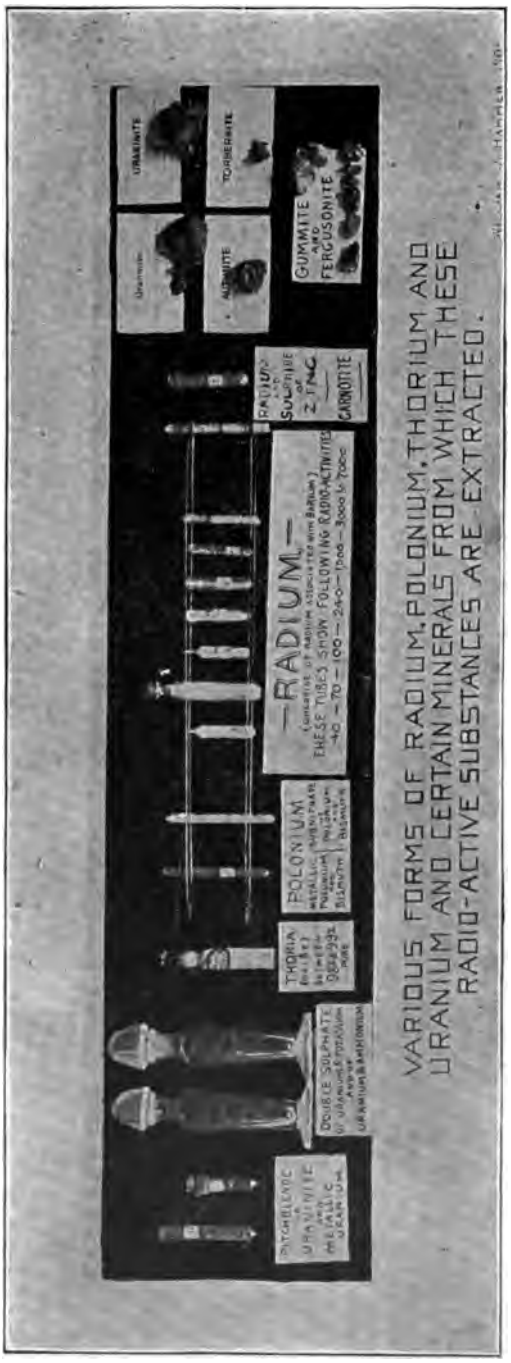


FIG. 2.—Radioactive Substances.

In 1899 was discovered the third substance in pitchblende, which possessed the chemical and other characteristics of thorium with which it was associated, and to this Debierne gave the name "Actinium." It is precipitated by ammonium sulph-hydrate. Crookes states that actinium is identical with the substance which he had isolated from uranium and to which he gave the name "uranium X." The rays from actinium are deviable.

Of the three substances to which I have referred, radium is by far the most important and is of extraordinary interest. It is doubtful whether any substance has been discovered in the history of the world of such stupendous interest and importance and possessing such puzzling characteristics as radium, which seems so at variance with well-established scientific theories as to the constitution of matter.

In Fig. 2 are shown in consecutive order from left to right, a tube containing pitchblende, or uraninite, from which radium, polonium and actinum as well as uranium are extracted; a tube containing metallic uranium made in the electric furnace by Moissan; two flasks containing double sulphate of uranium and potassium, and double sulphate of uranium and ammonium, these being the original salts of uranium with which Becquerel experimented when he discovered the Becquerel rays; a tube containing thorium, the most radioactive substance next to radium; two tubes of polonium and bismuth, one tube of metallic polonium and the other sub-nitrate of polonium; seven tubes of chloride of radium associated with barium ranging in radioactivity from 40 to 7,000; a tube containing radium and phosphorscent sulphide of zinc; and a tube containing carnotite, which, together with the samples shown of uraninite, autunite, torbernite, gummite and fergusonite, are among the mineral substances which are rich in radioactive materials. Other active minerals are orangite, euxenite, broggerite, cleveite, monazite, samarskite, xenotime, æschynite, niobite, arrhenite, hielmite, sipilite, chalcolite, etc.

In Fig. 3 the two tubes of polonium and the seven tubes of radium are shown about two-thirds their natural size.

Radium actinium and polonium, Prof. Curie states, possess an activity which is a million times that of uranium. Prof. Curie says radium emits exactly the same quantity of Becquerel rays when in the liquid air as it does at normal temperature of the atmosphere. The luminosity of the chloride of radium is stronger in the liquid air than in the atmosphere at a normal temperature.

POLONIUM
METALLIC POLONIUM AND BISMUTH
SUBNITRATE OF POLONIUM AND BISMUTH
—RADIUM—
(CHLORIDE OF RADIUM ASSOCIATED WITH BARIUM)
THESE TUBES SHOW FOLLOWING RADIO-ACTIVITIES
40 — 70 — 100 — 240 — 1,000 — 3,000 & 7,000
POLONIUM AND RADIUM

FIG. 3.—Showing two tubes of Metallic Polonium and Bismuth and Subnitrate of Polonium and Bismuth, and seven tubes of Chloride of Radium and Barium in the possession of the author. (About two-thirds natural size.)

My friend, Mr. R. R. Bowker, whom I met in Paris last Fall, told the writer that he had shortly before that been dining seated between Lord Kelvin and Prof. Becquerel, and that Lord Kelvin had turned to him and said, that the discovery of Becquerel radiations had placed the first question mark against the principle of conservation of energy which had been placed against it since that principle was enunciated.

Within the past month great interest has been attracted by the statement made by Profs. Curie and Laborde that radium maintains its own temperature at 1.5 Centigrade above its surroundings, this being equivalent to stating that half a pound of radium salt would evolve in one hour sufficient heat to equal that caused by the burning of one-third of a cubic foot of hydrogen gas; and that the heat evolved from pure radium salt is sufficient to melt more than its own weight of ice every hour. This evolution of heat, it is claimed, is going on constantly for indefinite periods and leaving the radium at the end of months of activity as potent as it was at the beginning. The problem therefore confronts the world of solving how radium can constantly throw off heat without combustion or without chemical change, as Prof. Curie says it does.

Messrs. Curie and Laborde employed a thermo-electric couple of iron and constantin, one of whose junctions is surrounded by radioactive barium chloride and the other by pure barium chloride. They used two small bulbs of the same dimensions, one containing one gramme of radiferous barium chloride containing about one-sixth of its weight in radium chloride and the other bulb containing one gramme of pure barium chloride.

The junctions of the thermo-electric couple are respectively placed in the center of each bulb, surrounded by the substances. The bulbs are isolated in air within the center of two small identical enclosures, surrounded in turn by a third, which is thermally insulated, and maintains itself at a practically uniform temperature, and under these conditions variations in the surrounding temperature are felt in the same manner at both junctions and do not affect the indications of the couple. Messrs. Curie and Laborde both thus observed a difference of temperature of 1.5 degrees C. between the radiferous barium chloride and the pure barium chloride, the former having the higher temperature. (*Comptes rendus*, March 16, 1903).

In a letter recently received by the author from Prof, Curie bearing upon the question of heat given off by radium Prof. Curie writes as follows: " Since the time I had the honor to see

you at our School of Physics and Chemistry I have continued to investigate into the radioactivity induced by radium and the way that radioactivity is disappearing in the course of time.

"In a study of another kind (in collaboration with M. Laborde) I found that the radium is setting off heat continually and in a very large amount; each gramme of the radium is setting off in each hour 100 small calories, or in other words it is setting off heat enough to melt in each hour its own weight in ice.

"Where is the source of this energy? Both Mme. Curie and myself are not able to go beyond some hypotheses; one of these consists in supposing the atoms of radium evolving and transforming into another simple body, and despite the extrem eslowness of that transformation which cannot be located during a year the amount of energy involved in that transformation is tremendous.

The second hypothesis consists in the supposition that radium is capable of capturing and utilizing some radiations of unknown nature which cross the space without our knowledge."

Profs. J. J. Thomson and Rutherford advance the theory that there is a succession of chemical changes going on causing the spontaneous projection of larger masses of material at enormous velocities, and that while certain portions are constantly dying out and becoming inert other portions are constantly increasing in strength and power.

Someone has remarked that for years we have been extracting uranium oxides, and pouring down the waste pipes and into the dust bins the more interesting and precious radioactive substances.

Although radium, polonium and actinium have been termed new elements, in the case of polonium and actinium they have as yet not been found in sufficiently pure state and in sufficient quantity to give a spectrum, and to prove conclusively that they are new elements. Prof. Curie has, however, stated emphatically that there is now no doubt of radium being a new element.

The tiny brown bulb which I hold in my hand is the duplicate of the one which Prof. Curie showed me at his laboratory last fall, which contained the only sample of chemically pure radium in the world, this being between two and three one-hundredths of a gramme; and it was the spectrum of that sample, showing only the lines characteristic of radium, as tested by Demarcay, which demonstrated it to be a new element. And with that sample, also, the atomic weight for radium of 225 was determined. The

atomic weight of the barium heretofore always associated with radium, but which in this sample had been eliminated, is but 157.

In answer to my inquiry as to its value, Prof. Curie said that 100,000 francs ($20,000) could not purchase this tiny sample.

I was enabled through the courtesy of Prof. Curie to secure from the Societé Centrale des Produits Chimique of Paris, some nine different preparations of radium and two of polonium, which I have here for your consideration. I was unable to secure any actinium; in fact, but a trace of this substance has thus far been secured.

If the lights are extinguished, and you will sit for a few moments in the dark, I will pass these tubes about the room that you may observe the bright light given off by certain of them. These samples which I have range from forty times the radio-activity of uranium (which is taken as a standard), up to 7,000.

The laboratory, where these substances are prepared, is under the control of Prof. Curie; and up to recent date, all radium of higher radio-activity than 7,000 has been retained for the experiments of M. and Mme. Curie and their associates; but I received a letter recently from Director P. Boulay of the Societé Centrale, in which I was informed that they will shortly put upon the market a preparation of radium, chemically pure or nearly so, at a cost of 30,000 francs ($6,000) per gramme or about $2,721,555.90 per pound.

Radium, while it has been spoken of as a metal, has never been secured in a metallic form, the usual form being as a chloride or bromide.

Prof. Curie told the writer that the result of all the work done in Germany and France in the past three years had only resulted in the securing of about one pound of radium; this including all grades or qualities. Prof. J. J. Thomson says there is far more gold in sea water than there is radium, polonium and actinium in pitchblende.

Prof. Curie took this ring which I have on my hand, which contains a small diamond, into his dark room and holding near it a small pill box containing about a gramme of radium, caused the stone to phosphoresce most beautifully. It was as if a lightened candle had been brought near to it. Prof Curie remarked that this showed that the stone was a genuine diamond; and if it had been paste there would have been no effect produced, and that radium therefore constituted an excellent means for testing the genuineness of diamonds.

According to M. and Mme. Curie, radium rays act in many ways like light. They reduce silver salts, peroxide of iron and bichromate of potash in presence of organic substances; they also color glass, porcelain and white paper, and they transform greenish yellow platino-cyanide of barium into a brown variety.

Giesel had prepared platino-cyanide of barium with a trace of radium. This spontaneously became brown, and it then polarized light like tourmaline. He also found that this colored rock salt just as cathode rays do, or the vapors of alkaline metals, and furthermore showed that radium salts, brought near the temples or to the closed eyes, produced a sensation of light.

M. Becquerel, referring to the chemical action of radium rays, says that radium and uranium rays act upon silver gelatino-bromide, but produce no effect upon Daguerre plates, or upon photographic papers, and says that colorations of glass, porcelain, paper and certain crystals, as well as the painful physiological effects also belong to this class of phenomena., He also calls attention to the transformation of white into red phosphorus in 24 hours, the reduction of mercuric chloride in the presence of oxalic acid with the precipitation of calomel, and finally the destruction of the germination power of seeds after long exposure.

Becquerel also shows that radium rays possess the same power as the electric spark, or the prolonged action of violet or ultra-violet rays, of restoring the phosphorescent properties under exposure to heat of a body deprived of them by over-heating.

Practically all the radium which has thus far reached this country, with the exception of that in the possession of the author, has been the German radium, and Prof. Curie tells the writer that he had tested all of the German productions, and he has found none of them to exceed a radioactivity of 300.

De Haen of Seelze near Hanover, Germany, and Giesel, of Brunswick, also have manufactured radium. De Haen recently informed the writer that the preparations he puts on the market cost ten and thirty shillings per gramme.

As indicative of the enormous difficulties to be encountered in procuring this wonderful substance, it is interesting to note that it takes 5,000 tons of uranium residues to produce a kilo (2.2 pounds) of radium; and the cost of handling these residues is $2,000 per ton. To secure the chemically pure radium is enormously expensive, and it would be impossible to do this by chemical analysis, therefore the far more sensitive electrical method is employed, and the Curies say that they can detect the presence

of a radioactive substance by the means of such a minute quantity that it would require 5,000 times this amount to show at all in the spectroscope. And it is stated that this method of electrical analysis is thousands of times more sensitive than spectrum analysis and millions of times more sensitive than chemical analysis.

In Fig. 4 is shown the " electrometer " method with which the Curies have studied the radioactivity of different substances. It consists of two plates, A and B, on the latter of which is placed the radioactive substance to be tested. This makes the air a conductor of electricity between the two plates. For measuring this degree of conductibility, the plate B is brought to a high potential by connecting it to one side of the storage battery P, the

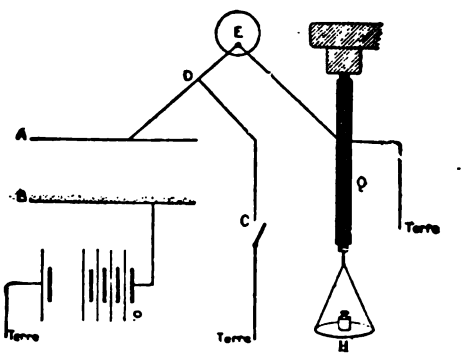


FIG. 4.—Apparatus employed by M. and Mme Curie in the study of radioactivity.

other side of which is connected to the ground. If the plate A is brought to the potential of the ground by the wire C-D., an electric current begins to flow between the two plates, A and B. The potential of plate A is shown by the electrometer E. If we cut this communication with the ground at C, the plate A becomes charged causing the electrometer to deviate. The speed deviation is proportionate to the intensity of the current and can serve for measuring it. But it is preferable to make this measurement by compensating the charge taken by plate A, so that the electrometer remains at zero. The charges which are extremely feeble can be compensated by means of a Piezo-electric quartz Q,

one armature of which is connected with the plate A, and the other armature grounded. The quartz plate is given a certain tension by weights placed on the plate H. This tension is gradually produced and gives a charge of a definite quantity of electricity which can be measured. The operation may be so regulated that there is a constant compensation between the quantity of electricity which passes through the condenser and that of the opposite sign furnished by the quartz. So we can measure in an absolute value the quantity of electricity passing through the condenser in a certain time.

Doubtless some loss is caused by the rays which pass directly through the condenser plates.

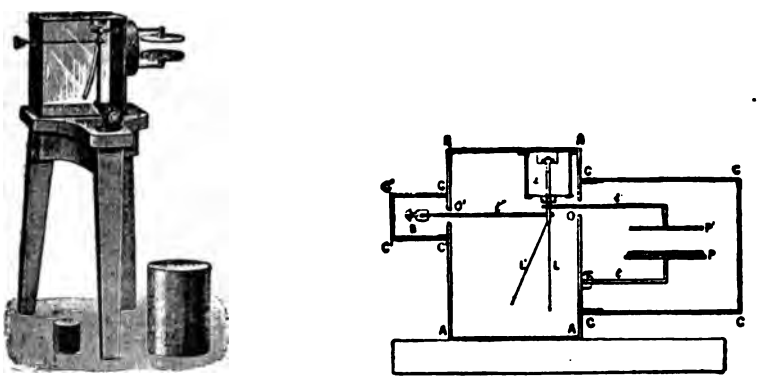


FIG. 5.—Curie's Electroscope for the study of Radio-activity.

Dolezalek has designed a very sensitive type of electrometer built by Bartels of Göttingen, a description of which may be found in *Verk. der Deutsche Physik Ges., iii* (1901).

It is well known that the leaves of a gold or aluminum foil electroscope will hold their charge in dry air indefinitely; but the Becquerel rays are found to dissipate the charge by ionization of the air, or rendering the air a conductor of electricity (the electroscope may also be discharged by Roentgen rays, cathode rays and ultra-violet light).

In Fig. 5 is show a form of electroscope devised by the Curies for the study of radioactive substances. Referring to the diagram to the right, it will be noted that the electroscope consists of a single movable sheet of gold or aluminum foil attached to a stationary sheet of copper L, being supported by the insulating

piece I. The radioactive substance to be tested is placed on the lower of the disks P and P′, preferably on a removable plate. The radiations make the air a conductor between these two plates The electroscope is charged by means of a stick of ebonite rubbed briskly and placed near the rod B. This deflects the sheet L′, from the vertical and it so remains for a very long time. When radioactive substances are brought near it, the gold or aluminum leaf is caused to lose its charge, and the leakage is observed by means of a stationary telescope shown in the left hand figure, which is provided with a micrometer scale. The time taken for the discharge of the electroscope is taken by means of a chronometer or watch. By suitable lighting, the front edge of the foil may be made to appear as a very fine line, and its position noted with great precision.

By examining the diagram it will be noted that the upper condenser plate is connected with the metallic case. Detachable metal cases are placed over the condenser plates and over the rod for charging the electroscope. Two of the sides of the case are of glass.

I have here a simple form of electroscope with leaves of aluminum foil, which serves to show the ionization of the air; when the radium is brought near the divergent leaves lose their charge of negative electricity and rapidly come together.

It is of paramount importance that the radioactive substance should be kept in a room distant from the electroscope.

At the present moment the clothes of every person in this room and all the walls of the room are radioactive by reason of the presence of the nine preparations of radium which I have here this evening.

Prof. Curie told the writer that it was often impossible for him to go near his instruments to make any measurements for hours, after being in the proximity of some radium, and those who have worked with this substance have found the greatest difficulty in keeping their tools and instruments and themselves free from the radioactivity imparted by the radium. The energy represented by radium is something enormous.

Elster and Geitel* have shown that a fine wire of any metal placed in the atmosphere and charged negatively from some source of current, say of 500 volts, causes the wire itself to become radioactive, and this radioactivity may be scraped off

* *Phys Zeit.*, 1901, ii., p. 590

and will affect photograph plates, ionize the air, etc. It cannot, however, be washed off. It is stated that lightning rods and even the leaves of trees all become radioactive: and it has been shown that falling rain and snow are for a time quite powerfully radioactive; and after they have fallen, a wire negatively electrified in the atmosphere has only a small amount of radioactivity, apparently showing that the rain and snow have carried the radioactive particles in the atmosphere down to the ground.

McLennan has made experiments with the negatively charged wire in Montreal and subsequently at the foot of Niagara Falls; and has found the result about one-sixth as powerful in the latter place as in the former; and he has also shown that it was not necessary to electrify the wire used at Niagara Falls, as it received a sufficient charge from the electricity in the atmosphere.

McLennan found that rain caught in a vessel and immediately evaporated to dryness imparted radioactivity to the vessel in which it was evaporated.

Ordinary water when evaporated and rain water which has stood for several hours before being boiled down do not yield any radioactivity.

As an evidence of radioactivity imparted to another substance by radium, I have here some pieces of cardboard which constituted the box which held my samples of radium for several months. The box becoming injured, I broke it up, fortunately saving the pieces; and six days after the radium had been removed, I looked up the pieces and was surprised to find them luminous in the dark. Subsequently I tried their effect on a photograph plate; but did not succeed in getting any impression. Three weeks later it occurred to me to try and stimulate the radioactivity of the cardboard, which had not been near radium for over a month, by burning magnesium wire, when I found I could make the cardboard brighter than it had been in the first place. I have also stimulated the radioactivity by sparks from a coil, especially when producing ultra-violet rays, by using a condenser bridged across the secondary and employing pure iron electrodes. I tried the burning magnesium with various samples of cardboard which had not been exposed to the radium, and there was no phosphorescence. It has already been stated that various substances which become radioactive retain that property for a short time only, and it is interesting to note its retention for such a long period of time and to note this

ability to stimulate and make visible the imparted radioactivity.

This experiment suggests the discovery made by Prof. E. Wiedemann that a mixture of sulphide of calcium with a little sulphate of manganese is not altered when exposed to cathode rays; but some time after its exposure it bursts into a vivid greenish glow when slightly heated; and to this phenomenon he has given the name " thermo-luminescence."

Prof. S. P. Thompson also showed that fluorspar which by prolonged heating has lost its luminescing power, regains the power of thermo-luminescence on exposure to Roentgen rays when reheated.

Prof. Trowbridge also finds that this restoration is also effected by exposure to the electric glow discharge, but not by exposure to ultra-violet light.

It is also stated that an object coated with calcium sulphide and exposed to the sunlight will phosphoresce about ten hours; and even after it has lost its luminosity, it can be caused to again give light by heating first by the hand, then over a water bath, and finally on a hot stove.

McLennan has found a very large number of salts are brought into a condition by cathode rays, in which warming makes them radioactive for a short time, the supply of negatively charged particles discharged from the surface coming to an end.

Prof. Rutherford of Montreal, who has given a great deal of attention to radioactive substances, particularly to investigations into thorium, which next to radium is the most radioactive substance yet discovered, has found that by electrifying a wire negatively with a current of 500 volts connecting the positive pole to the ground; and by connecting a sample of thorium to the earth, that the thorium particles were attracted to the negatively charged wire, producing a greater radio-activity than he had ever found in any thorium preparation which he had made.

I have here a sample of oxide of thorium, the radioactivity of which was discovered independently by Schmidt and Curie. This sample is between 98 and 99 per cent. purity. From this body Prof. Rutherford has isolated a substance which he calls " ThX;" and extraordinary as it may seem, it has been found after separation of the active constituents represented by the ThX from the thorium, that the ThX loses its radioactivity, and this is taken up by the thorium in exactly the amount which the other loses.

Sir William Crookes has also separated a non-uranium residue

from uranium, leaving the latter without radioactivity. Whilst the whole of the radioactivity has been concentrated in the residue to which the name UrX was given, Crookes, as already stated, claims that Actinium is but another name for his UrX.

The only case of radioactivity induced by cathode rays in a neutral substance has been that of bismuth, discovered by Villari.

Prof. Curie has discovered that radioactive gas emanates from radium; and Rutherford has discovered the gaseous emanations from thorium, Messrs. Rutherford and Soddy have investigated extensively these emanations, and they have succeeded in condensing them at the temperature of liquid air. A preliminary account appears in the proceedings of the Chemical Society of London for December, and Prof. Rutherford writes me that the full paper will shortly appear in the Philosophical Magazine; and he states furthermore that in his opinion this proves beyond doubt the gaseous nature of the emanations.

The serious physiological effects of radium are well known, and Messrs. Giesel, Becquerel, the Curies and others, have given important evidence thereof. As stated in the appendix of a paper read by the writer at the 159th meeting of the INSTITUTE on January 3, 1902, dealing with the subject of radioactivity, Prof. Curie told the writer that he would not care to trust himself in a room with a kilo of pure radium, as it would burn all the skin off his body, destroy his eyesight and probably kill him. The writer felt the effects for weeks of a slight burn from inadvertently carrying a wooden box containing eight tiny sealed glass tubes of radium under his arm for several hours.

Mr. W. E. Hidden has called the attention of the writer to some phenomena which he has observed in a mine in Barringer's Hill, Llano County, Texas, which mine contains yttrium, thorium and uranium. Pockets of ore have been found, ranging from a few ounces up to a capacity of 70 kilos, which were the nuclei or focal points of rigid lines radiating in every possible direction. These lines penetrating great masses of quartz and orthoclase feldspar, and gigantic pegmatyt, to distance often of several feet, in some cases of from five to eight feet, he has observed that these radial lines were fissures and bore no relation to the natural cleavage or the crystalline form of the huge rock masses in which they existed. Easy parting took place along these radial lines, making the ore quickly available.

It is Mr. Hidden's theory that, as these lines directed to ores

rich in uranium and thorium, both well known sources of radium, etc., the phenomenon is due to an electric or other effect of radioactivity; it being untenable, he believes, to explain this phenomenon on the basis of expansion or contraction.

The slide which I will show on the screen shows clearly a pocket of ore with the lines radiating therefrom in all directions.

Eighteen years ago, while in Italy, the author visited the celebrated aquarium in Naples, which is probably the finest in the world; and while there was enabled to test the shocking abilities of the Electric Ray, or " Torpedo Galvani " and was astonished at the tremendous shock which he received; and in this connection, it is interesting to call attention to the fact that there are fifty or more fishes which are known to possess this property of giving powerful shocks. The " Gymnotus " or Electric Eel, and the " Torpedo Galvani " or Electric Ray being the best known of these.

It will be recollected that Faraday drew a powerful spark from a Gymnotus at the Polytechnicum, London, and he estimated the shock to be equivalent to that given by a battery of leyden jars of 3,500 square inches of surface. And many writers have referred to the ability of these electric fishes to give powerful shock for a long period of time. D'Arsonval has caused them to light incandescent lamps and they have been known to magnetize needles and decompose water by the electricity they produce. These fishes doubtless using this faculty as a means of defence and also for procuring food. My object in mentioning this is to state that last Fall I again visited Naples and thinking that perhaps an electric torpedo was on exhibition, it occurred to me to take with me some half dozen tubes of radium which I had in my bag, and see whether the radium had any effect upon the power of the fish to give powerful shocks. The fish, as at the time of my previous visit, was lying in a shallow wooden box containing wet sand and a small amount of water. By taking hold of the side of the fish and pressing with the thumb on one side and the fingers on the other, or by either pinching or tapping the fish, the cells with which the fish was equipped discharged themselves and gave a shock sufficient to twist one's arm very badly. After the members of our party had each received a shock, and as soon as a few persons present had gone away, I laid the six tubes of radium on the fish (which is shaped very much like a flounder), leaving them there for about twenty minutes. I then replaced the tubes in the box, and taking hold

of the fish tried for fifteen minutes to get it to give me a shock by tapping or pinching in the same manner as previously done when the fish gave off shocks, and without receiving the slightest shock. Now, I am prepared to admit that the fish might have been "entirely out of shocks"; still, it is well known that these fishes will continue to give out shocks for a very long period of time, one authority reporting 360 shocks in seven minutes' time; but after exposing the fish to the radium, I could get absolutely no manifestation; and in this connection, it is to be remembered that the physiological effects of radium, such as burning, destroying microbic life, producing the sensation of light when a tube is held against the closed eye or temples (which is doubtless largely due to the phosphorescence of the pupil of the eye, but which may also affect the nerve centers), and also the electrical effects, where charged bodies are caused to give off their charge by the ionization of the air; and one must also remember the very numerous chemical effects and the destruction of the germinating power of seeds, the changing of oxygen into ozone, and various other phenomena of radium which would lead one to wonder whether the radium did not affect the ability of the fish to give off electric shocks, perhaps producing a partial paralysis.

The experiment is of some interest, and may be perhaps repeated by others who have better facilities than I to continue the investigation. I have sometimes wondered how that fish was getting along in Naples; though I believe the waters of the Mediterranean abound in them.

Note—Since writing the above description of his own experiments, the writer has learned of the recent experiments conducted by Prof. Curie, in which a few milligrams of radium introduced beneath the skin of a mouse near the vertebral column produced death by paralysis in three hours; and tubes of radium placed in contact with the back of the necks of guinea pigs have killed or paralyzed these animals in a few hours, according to the length of exposure to its fatal radiations.

As illustrating the action of radium rays upon bacteria, E. Aschkinass and W. Caspari speak of exposing cultures of *micrococus prodigiosus* to a radium preparation, and state that the rays killed the germs very effectively in about three hours.

The work of Rutherford, the Curies, Becquerel and others has demonstrated that there are three entirely distinct types of rays emanating from radium (Rutherford having first pointed out that uranium possessed two separate types of rays, "α" and "β,"

the former easily absorbed even by gases, whilst the latter are very penetrating and but little absorbed by gas). Those which constitute by far the most important class are the "α" rays. They constitute the major proportion of the rays, and are those which produce the greatest portion of the ionization of the gas, which has been observed under experimental conditions.

These "α" rays possess in common certain characteristics of Roentgen rays, and by many have been thought to be Roentgen rays. I shall call your attention later to certain effects which are identical with those produced by Roentgen or X-rays. They have been considered absolutely non-deviable, as X-rays have been held to be.

Rutherford has, however, recently shown that in a very powerful magnetic field he could deflect about 30 per cent. of the rays, and in experiments now being conducted with a strong electric field, he has been able to deflect about 45 per cent. of the "α" rays. The "α" rays are readily absorbed, and a thin screen of metal will serve to cut off the greater portion of them.

In this connection I would state that Mr. Tesla informed the writer recently of an experiment he had made in which he had succeeded in deflecting the X-rays themselves, and M. Blondelot has recently claimed as the result of his experiments that X-rays are susceptible of polarization. If this is so, it is argued they may be shown to be ordinary light waves of extremely short wave length.

Strutt and Crookes have suggested that the "α" rays consist of positively electrified particles, and this view Rutherford supports, calling attention to the fact that they possess characteristics similar to the "Canal Strahlen" of Goldstein. These Goldstein rays have been shown by Wien to be positively charged particles, moving at high velocities.

Rutherford, as a result of his most recent observations, considers that the "α" rays move at much higher velocity than the Goldstein rays; and he estimates that the energy of the "α" rays is a thousand times greater than that of the "β" rays.

Rutherford says all the radioactive substances, including polonium, as well as excited bodies and the emanations, give out "α" rays.

The "β" rays are much more penetrative and much longer, and in every particular correspond to the characteristics of cathode rays. They are readily deflected by a magnet. They

discharge electrified bodies by ionization of the air, affect photograph plates, etc.

M. Villard, in 1899, proved that the cathode rays are negatively electrified corpuscles or fragments of atomic hydrogen, and these corpuscles, as they were named by J. J. Thomson, which he has shown to be one one-thousandth of the mass of the hydrogen atom, are projected from the cathode at a speed approximating 70,000 miles per second.

The " γ " rays are the rays possessing the greatest penetrative effect. They will excite or produce radioactivity through the air at a distance of three or four feet or more.

Some recent experiments made by Rutherford show the relative penetration of the three classes of rays through aluminum sheets of varying thicknesses, before a loss is observed of half of the intensity, and this shows for the

" α " rays a thickness of aluminum of .0005 cm.
" β " rays a thickness of aluminum of .05 cm.
" γ " rays a thickness of aluminum of 8. cm.

Mr. Rutherford, who has conducted most painstaking investigations into the penetrative character of the radiations from uranium, radium, thorium, etc., recently wrote the author in answer to some questions on the subject, that he had found that the radium rays were reduced to half value after passing through 1 cm. of lead, 1 inch of iron and about 8 inches of water, the radiation being reduced to about 1 per cent. of its original value, after passing through 7 cm. of lead, 7 inches of iron and 56 inches of water.

In the lantern slide thrown on the screen is an interesting illustration of the effect of magnetism on the deflectable rays from radium. There are four large steel magnets, two being placed opposed to each other, and the other two so that unlike poles are opposite to each other, making a strong field of force between the two magnets. I have placed six tubes of radium a short distance above the magnets and in a line running across and between the poles of the two pairs of magnets. It will be seen that the magnetic rays in the case of one pair of magnets have repelled the radium rays so that the negative is but slightly affected. Whereas, in the case of the other pair of magnets the radium rays have been attracted by the magnets affecting considerably the negative around the pole pieces.

Prof. Curie states that half of the induced radioactivity, when exposed to the air, is lost in certain substances in half an hour;

but in a closed vessel, where the air has been made radioactive, however, this radioactivity has not lost half of its strength, even after four days' time.

It is desirable to keep radium free from moisture, preferably in sealed glass tubes. It readily takes up moisture, and then soon loses its luminosity, which may, however, be regained by dissolving and precipitating the substance and thoroughly drying it. The luminosity may also be considerably heightened by subjecting the radium to high temperatures.

Polonium like uranium does not possess the power of exciting, radioactivity, as it does not give off any emanations; whereas, in the case of radium and thorium, there is an actual emanation. producing radioactivity in surrounding objects by the deposit of radioactive matter.

When one considers the remarkable effects produced by radium it would almost seem that it is matter tearing itself into tiny pieces, and projecting these infinitesimally small particles through all matter at a speed from half to even the full speed of light, and rendering all substances about it radioactive, and still without appreciable loss in weight in the original substance, and without disparagement of the accepted wave theory of light one naturally " harks back " to Newton's corpuscular theory of light.

While various theories have been advanced to account for the phenomena of radium, there remain many things which have not been satisfactorily accounted for; and perhaps the subject which has been most widely discussed is the loss in weight of radioactive substances.

At the British Association meeting last summer, Prof. J. J. Thomson is reported to have stated that if a square centimeter of surface were covered with pure radium, it would only lose in weight one thousandth of a milligram in a million years. This is in accordance with the previous statements made by Becquerel.

Later in the year, A. Heydweiller, of the Royal University, Munster, Germany, stated that he had been testing a sample of De Haen's preparation of radium, and found that it lost in weight two one-hundredths of a milligram per day for fifty days, and a whole milligram in that period. (*Phys, Zeit*, Oct. 15, 1902.)

The great discrepancy in the statements on this important subject, led the writer to enter into correspondence with Profs. J. J. Thomson, Henri Becquerel, Lord Kelvin, Sir William Crookes, P. Curie and A. Heydweiller, which resulted in the following expression of views.

Prof. Thomson was inclined to think that from the magnitude of loss found by Heydweiller, it must be due to some secondary effect, and he stated that he could not speak with certainty without a greater knowledge of the details of the experiments. As accounting for the results he, however, drew attention to the well-known coloration of glass by radium, by remarking, " One point, however, that ought to be attended to in these experiments is the effect of the radiation from radium on glass. Glass, as is well known, gets deeply colored when in contact with radium. It seems to me possible that the glass might be charged right through. If this were the case, it is possible that reactions might occur between the glass and the air, producing volatile substances and a loss of weight. I only throw this out with hesitation, for as I said before, I am not familiar with the details of the experiments."

Prof. Becquerel informed the writer that he knew nothing reliable regarding the experiments of Heydweiller, and called attention to his original paper on this subject which appeared in the *Comptes rendus* of March 26, 1900, adding, " I believe I am the first to have published an estimate in this way which could only result from my own experiments. The loss of one milligram per square centimeter requires one thousand million years. This statement refers only to the part of the deviable portion of the radiation to which measurements were applied; but this is only a part of the total loss. The deviable radiations comprise rays ranging from 10^{9} and 3.10^{10} c.m Besides, there is also all the non-deviable portion, either penetrating or absorbing, which corresponds to a notable loss of energy; and in addition, if the emanation is of material importance, which seems quite probable, the loss on this account would be a thousand times greater. These estimates are but theoretical, for it is probable that at least a portion of the mass calculated or estimated as material is apparent and corresponds to the effects of induction."

In response to an expression of view from Sir William Crookes on a theory to satisfactorily account for the phenomena of radioactive substances, he wrote as follows: " You will find them fully given in my address to the British Association at their Bristol meeting in 1898. I have not seen any special reason to alter the views there propounded "; and in writing on the subject of Heydweiller's experiments, Prof. Crookes says, " I do not think the experiments of Heydweiller have been corroborated by other observers; and there are many sources of error in his

experiments which I should like to see discussed before giving credence to it. Personally, I find no loss of weight in a rich sample of radium compound during continuous weighings extending over many months. I should be inclined to agree with Becquerel and J. J. Thomson."

Lord Kelvin wrote that he was sorry not to have been able to make any experiments on radioactive substances which could allow him to offer any opinion that would be helpful on the subject, and added, " What you tell me regarding radium and your correspondence with Prof. J. J. Thomson is very interesting."

On this point Prof. Curie recently wrote me as follows: "I never did believe in the exactness of Mr. Heydweiller's experiments; and I always thought he did not take care enough to avoid some source of errors. In fact, with a substance considerably stronger than his own I only obtained a reduction in weight of 1-10 of a milligram in four months for several decigrams of substance, and as the tubes were used at the same time in several experiments, that loss of weight does not allow me to affirm that radium is losing weight spontaneously. I believe, meanwhile, as does Mr. Heydweiller, that the question cannot be answered in any other than an experimental way, and that all speculative theories are of small interest. I have published my recent researches in the *Comptes Rendus de l' Acadamie des Sciences de Paris*."

As regards the published statements of Prof. Heydweiller's experiments, the writer can state that he is most reliably informed that a mishap occurred during his experiments which resulted in one of the tubes becoming cracked, which was not observed until later; and that this practically nullified the results published; and, in fact, they have not been confirmed by subsequent tests; but, on the other hand, they tend to corroborate the experiments of Becquerel and the statements made by him, Sir William Crookes, J. J. Thomson and others. The writer is also informed that Prof. Heydweiller is continuing further experiments, the results of which will doubtless be published when his investigations are complete.

As bearing upon the coloration of glass already referred to, I hold in my hand a flask which I secured at the laboratory in Paris, which has contained radium, and has been most beautifully colored a deep violet. I also have several tubes in which radium has been kept, which are similarly colored, and in this connection I would call attention to the fact that X-ray tubes which have

been in use for a considerable time become similarly colored, forming another link between the Roentgen rays and radium rays.

I also have here a tiny bulb of glass which is colored a deep brown. I have seen only one other piece of glass colored in this way, this being due to the difference in the chemical constituents of the glass (though in some cases the glass subsequently turns a violet color). This is a duplicate of the tiny tube which Prof. Curie showed the writer, which contained between two and three one-hundredths of a gramme of chemically pure radium.

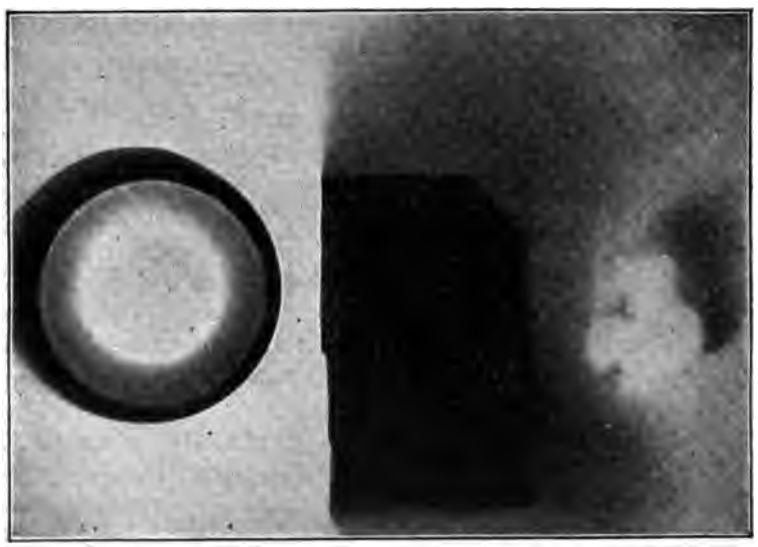


FIG. 6.—Radiograph Made by Radium of a Disc for Testing Radioactivity, a Block of Rock-salt and a Lump of Pitch-blende.

It is interesting to note that the Becquerel rays induce activity which persists, whereas that excited by Roentgen rays ceases immediately on the removal of the rays.

As illustrating the X-ray character of radium rays I would call your attention to Fig. 6, in the center of which is shown a block of rock salt. The original sample was about one inch thick, and was so transparent that a person's features might be seen through it. The rock salt is not only transparent to ordinary light, but also to ultra-violet light, whereas it is very opaque to X-rays.

Mrs. Hammer, appreciating the serious physiological effects of radium, has made the interesting suggestion that radium be kept in boxes made of rock salt, and the author is now having such a receptacle made. This might be even more satisfactory than a lead box. It would be interesting to note the change in the temperature of such a box or vial which so well intercepts the Radium rays.

The illustration referred to was made by placing the rock salt on a photograph plate with the radium some 5 inches above it.

To the right of the rock salt is shown a piece of uraninite (pitchblende), from which radium is extracted. You will note that not only has the mineral been photographed by the radium above it, but the radium has acted on the radioactive constituents of the pitchblende and caused this to affect the plate.

The disk shown at the left of the cut is one made in Paris for the examination of radioactive substances. I have one of these here, and it consists of a rim of brass, enclosing a brass washer with a glass disk at the center. The opposite face is covered with aluminum foil, and between the aluminum and the glass is placed some radium of 1,000 radioactivity. Substances which it is desired to examine are laid on this disk. It is, however, a rather crude piece of apparatus; but in the cut shown not only has the disk been photographed by the raidum 5 inches above it, but the radium inside of the disk has penetrated through the aluminum and fogged the plate.

In Fig. 7 are shown some interesting effects of the radium rays in affecting a photograph negative after passing through lenses. The lenses " A " and " B " are plano-convex condensing lenses, one being placed with the flat surface down, and the other with the convex surface down. " C " is a double convex lens of crystal. " D " is a plano-convex lens of uranium glass and " E " represents an ordinary glass prism.

It is stated that radium rays cannot be reflected, refracted or polarized. Those familiar with the phenomena of light will, I feel sure, be interested in the above photograph.

In Fig. 8 is shown another illustration of the penetrative character of the rays, it being a thick lead box containing six tubes of radium, ranging from a radioactivity of 40 to 7,000; this box being laid upon a large steel magnet $\frac{3}{8}$ of an inch thick. You will note the degree of penetration of both the lead and the steel varies according to the radioactivity of the radium in the various tubes. The exposure was made in twenty-two hours.

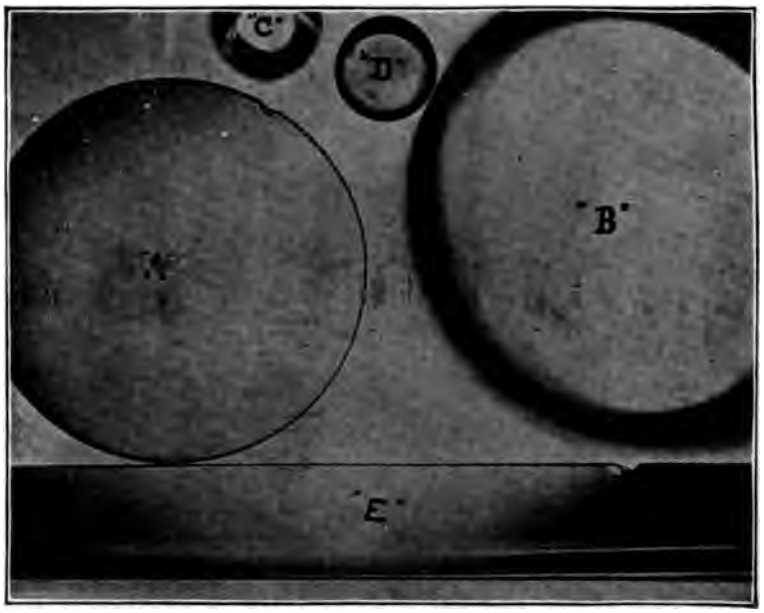


FIG. 7. Radiographs of Various Types of Lenses Made by Radium.

FIG 8.—Radiograph showing Degrees of Penetration of a thick sheet of Lead and a Steel Magnet by Tubes of Radium of Different Radioactivities.

Fig. 9 illustrates the penetration of the rays through black paper, the steel tool shown having been laid on the plate covered with two thicknesses of heavy black paper, such as used for

FIG. 9.—Radiograph of Steel Tool made by Radium Acting Through Two Thick X-ray Plate Envelopes.

wrapping X-ray plates; a single sheet of which is entirely impervious to light. The exposure was made in twenty-four hours.

Fig. 10 shows a mouse which was radiographed in twenty-four hours by laying it directly on a plate, which was, as in the case of

FIG. 10.—Radiograph of a Mouse Made by Radium in Twenty-four Hours.

other experiments, placed in the bottom of a trunk, the trays being replaced and the trunk wrapped in three thick rugs, and kept in a dark room for twenty-four hours.

The radiograph of the mouse shown in Fig. 11 represents a mouse caught on another occasion, in which I placed the mouse, trap and all on the plate, leaving it there for three days. The trap was an ordinary 6 cent trap; and it will be noted that the metal parts of the trap are shown opaque, whereas the portion of the wood nearest to the radium is shown absolutely transparent, as if it had been exposed to X-rays. In the original photograph

the mouse is also shown somewhat transparent, indicating slightly the bones.

I also show you in Fig. 12 and upon the screen a slide which I have made of a radiograph of a human hand. This was exposed for eight days, and bears resemblance to an X-ray picture which has been overexposed. In making a faint print of this, a slight trace of the bones is shown and the embalming material employed is brought out strongly. This is, perhaps, the first picture made of the human hand by means of radium and it would not have been possible, of course, to have exposed a living person to these rays for even a small percentage of this length

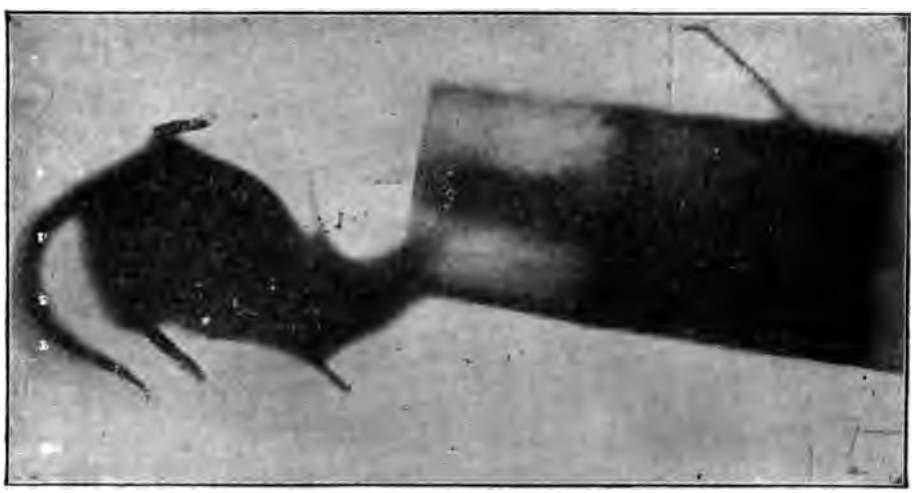


FIG. 11.—Radiograph of Mouse Caught in Trap and Exposed to Tube of Radium for Three Days. (Note Transparency of Wood, as with X-rays).

of time. Perhaps subsequent experiments will bring out much more strongly the bone structure (the irregularity in the fingers is due to their being somewhat cramped).

As X-rays will excite phosphorescence in many substances, one would naturally wonder whether there were any X-ray characteristics in phosphorescent substances.

An interesting experiment is shown in Figs. 13 and 14. In the former experiment, I have placed strips of various metals, such as brass, iron, copper, tin, lead, tin foil, aluminum, platinum, magnesium, etc. and strips of carbon, vulcanite, glass, mica and celluloid.

FIG. 12.—Radiograph of a human hand made by Radium in 8 days' time

FIG. 13.—Photograph Made by Phosphorescent Sulphide of Calcium of Iron, Brass, Copper, Tin, Lead, Aluminum, Platinum, Tinfoil, Magnesium, Carbon, Glass, Mica, Celluloid, Vulcanite, etc., and Strip of Black Paper. (See Fig. 14.)

Across the middle of the plate I have placed a strip of thick black paper cut from an X-ray plate envelope. I then sprinkled over the entire plate by means of a sieve sulphide of calcium, which I had made brilliantly phosphorescent by exposure to burning magnesium ribbon. The only substances which allowed the light to pass through at all were the glass, mica and celluloid, the other substances, including the paper, being very opaque, showing apparently only the presence of ordinary light rays. This plate was placed for twenty-four hours in a dark room.

FIG. 14.—Radiograph Made by Radium of Same Substances as in Fig. 9. Note Black Paper is Transparent, as are Certain of the Other Substances especially those directly below the Radium.

In Fig. 14 are shown some substances similarly arranged, but exposed to a tiny tube of radium of 7,000 radioactivity, which was placed 3 inches above the plate and near the center. The exposure was made for twenty-five hours; and it will be noted that the strip of black paper has entirely disappeared, and the various substances underneath it have been penetrated to a greater or less degree; particularly, those nearest to the radium.

A bibliography of "Radio-Activity," even at this early date,

would be very extensive, among the publications containing the most important contributions are *The Phil. Mag., Comptes Rendus, Ann. der Physik, Revue Gen des Sciences, Nature, Jour. de Phys., Soc. Francaise Phys. Bulletin, Chem. News, Phys. Ges. Verk., Phys. Zeit, Science Abstracts, Wied, Ann., Proc. Royal Soc, etc.*

The Properties and Applications of Selenium.

The extraordinary property which selenium possesses of varying its electrical resistance on exposure to light is a phenomenon which has been known for a long time but the commercial applications of this peculiar property possessed by selenium have not been properly appreciated up to the present time.

It is my purpose to invite your attention this evening to a number of applications of selenium which the writer believes will prove of no small interest to the electrical engineering profession, and perhaps stimulate investigations in this most promising field.

The Swedish scientist, Berzelius, discovered selenium in 1817, as a by-product from the distillation of sulphuric acid from iron pyrites. The proximity of the earth and moon suggested to Berzelius the name "Selenium" after the Greek "selene" (moon); this being the result also of the striking similarity of the properties of selenium with those of tellurium, which is a term derived from the Latin "Tellus," (earth.) Its atomic weight is 79.5; specific gravity when crystalized, 4.788; its observed vapor specific gravity at 2588° F. 5.68. It is a non-metallic element, which possesses characteristics similar to phosphorus, sulphur and tellurium. When melted at 212° Centigrade and allowed to cool rapidly, it forms a brown amorphous mass of conchoidal fracture. In this condition it is a high class insulator. It has been said that a small piece of it would represent the resistance of a wire stretched from the earth to the sun. When heated for quite a time at a temperature of 100° Centigrade, selenium becomes a conductor of electricity to a limited degree, this increasing with an increase of current and varying according to the direction. Selenium has neither taste nor smell.

The red vapor rising from selenium when subject to intense heat is exceedingly poisonous, and care should therefore be taken when experimenting with selenium in liquid form.

Selenium is usually supplied commercially in a vitreous form. Here are some samples of it, and you will note that it is as structureless as glass and resembles black sealing wax. I also

have here some amorphous selenium in which form it is a finely divided brick-red powder. This changes into vitreous selenium when exposed to a temperature of from 80° to 100° Centigrade. In order to obtain crystalline selenium, in which form it is useful for selenium cells, it must be kept, as already stated, at from 100° to 200° Centigrade for some time, the black mass being changed into a hard slate-colored metallic looking substance. In this form even the thinnest films are opaque to light, whereas in the vitreous form the film would be transparent and ruby red in color. I have some of these films here for your examination.

Selenium is to-day employed to a considerable extent for the coloration of glass.

In 1851 Hittorf first discovered the effects of temperature on selenium; but it was not until February 12, 1873, that Mr. Willoughby Smith sent a communication to President Latimer Clark, of the Society of Telegraph Engineers of London, calling attention to the effect of light in reducing the resistance of selenium. An assistant of Mr. Willoughby Smith, a Mr. May, who was a telegraph clerk at Valencia, called attention to the fact that some pencils of selenium which had been used to give a high resistance in connection with some of the cable testing work conducted by Mr. Willoughby Smith, showed a marked change in resistance when the sliding cover of the box which held the selenium was removed, and the selenium was exposed to sunlight. These selenium pencils varied in length from 5 to 10 centimeters, and were 1 to 1½ mm. in diameter; they were hermetically sealed in glass tubes with connecting wires of platinum at each end. Little credence was given to the original announcement; it was only after Earl Ross verified this statement, and proved that the action was due solely to light, and showed the effects of the light of different portions of the spectrum, that it met with serious consideration. Since that time much work has been done in investigating the properties of selenium, especially by Messrs. Shelford Bidwell, J. W. Giltay, Lord Ross and Sale, Draper and Moss, Hittorf, Adams and Day, Ayrton and Perry, Sir W. C. Siemens, Werner Siemens, Mercadier, Fritts, Minchin, Ruhmer, Webb, Bell and Tainter, and many others.

Alexander Graham Bell some twenty years ago made some interesting experiments with his radiophone, a diagram of which is shown in Fig. 15, in which a mica or glass diaphragm covered with a silvered foil was used to reflect a powerful beam of light upon a selenium cell placed in the focus of a silvered reflector.

To the selenium cell were connected a pair of telephones and a battery. At the back of the silvered diaphragm was a flexible tube and mouth piece into which words were spoken. The sound waves causing the diaphragm to vibrate sent pulsations of the reflected light upon the selenium cell, producing corresponding variations in its resistance and reproducing audible sounds in the telephone. Prof. Bell used this over very short distances only.

In 18 8 Prof. H. T. Simon of the University of Göttingen, discovered that an arc lamp, the circuit of which was in proximity to a telephone circuit, was caused to vibrate very perceptibly and he devised his interesting speaking arc by means of which he superimposed the sound waves produced by the telephone upon the circuit in which the arc was placed. He connected the lamp circuit with the secondary winding of an induction coil,

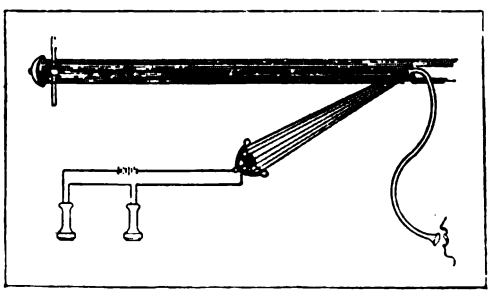


Fig. 15.—Prof. Bell's Radiophone.

the primary circuit being connected with the carbon transmitter, and a battery. The sounds thus produced originally were very weak; but by employing a suitable carbon microphone the sound was reproduced to large audiences. Conversely, the arc could also be used in conjunction with telephone receivers to receive sounds.

It is also found that the transmitter battery may be omitted, and a shunt taken from the arc circuit may be used with the transmitter and a suitable resistance. Again, this resistance may be displaced by storage batteries; and in this case to secure the most satisfactory results, self-induction (" reaction coils ") should be placed in the circuit of the arc lamp, allowing the direct current to pass without obstruction, but offering extremely high resistance to the alternating currents produced by the carbon transmitter. By compensating in this way, any disadvantage in the use of the shunt is done away with.

The transmitter may also be placed in shunt with the reaction coil instead of in shunt connection with the arc lamp, and this has the advantage that the rheostat used with the storage batteries may be omitted, provided the windings of the reaction coil are suitable for use as a resistance. By this arrangement, the lack of self-induction in the transmitter circuit permits of a very clear and distinct reproduction, sufficient to be heard by large audiences.

Mr. W. Duddell, of England, has made some most succesful talking arcs, which the writer had the privilege of seeing in London over two years ago. In his arrangement in the secondary circuit is placed a condenser, which prevents the lamp current entering the induction coil; but allows the induction current in the transmitter circuit to pass without obstruction; and this arrangement has the effect of greatly increasing the sound. By employing a condenser of from three to five microfarads, he compensates for the difference of phase produced by the self-induction in the circuit, thus producing the highest effect in the arc.

When Duddell uses the arc for transmitting sound waves, he employs in the shunt circuit to the arc a condenser and receiving telephone. It is advisable to employ as long an arc as possible. It has also been found that the Moore vacuum tube and the various types of mercury arc, such as Arons, Hewitt and Weintraub, are very suitable for this class of work, as well as the carbon arc; and where the latter is employed, either cored or treated carbons are advisable.

The theory advanced to account for the phenomena of the speaking arc, is that variations in temperature of the arc are produced by the variations of the current, and the change in the Joule effect produces a corresponding variation in the volume of the conductive gases in the arc.

The most successful and most extensive experiments which have been made with the speaking arc are those of Mr. Ernest Ruhmer, of Berlin, Germany, who has employed it in conjunction with his selenium cells for wireless telephony and with remarkable success. In Fig. 16 is shown the apparatus employed by Mr. Ruhmer, with which he has succeeded in transmitting speech over a beam of light 4½ miles in length*. Mr. Ruhmer's apparatus is shown in the illustrations thrown upon the screen,

* Mr. Ruhmer has recently written the author that he has succeeded in talking over a beam of light a distance of over ten miles.

and in Fig. 17. In his experiments he employed an arc lamp with a flaring arc 6 to 10 mm. long, using an e.m.f. of 220 volts; the current varied from 4 to 5 amperes at 1 to 2 k.m., 8 to 10 amperes for 3 to 4 k.m., and 12 to 16 amperes for 5 to 7 k.m., and the resistance of his selenium cell was 120,000 ohms in the dark, this falling to 600 ohms in full sunlight. For the transmitting end, Mr. Ruhmer employs a carbon transmitter and a battery superimposing waves on the arc light circuit; and the beam of light is reflected to some distant point, where it is received by a parabolic reflector; in the focus of which is placed a selenium cell connected with a battery and a pair of very sensitive telephone receivers.

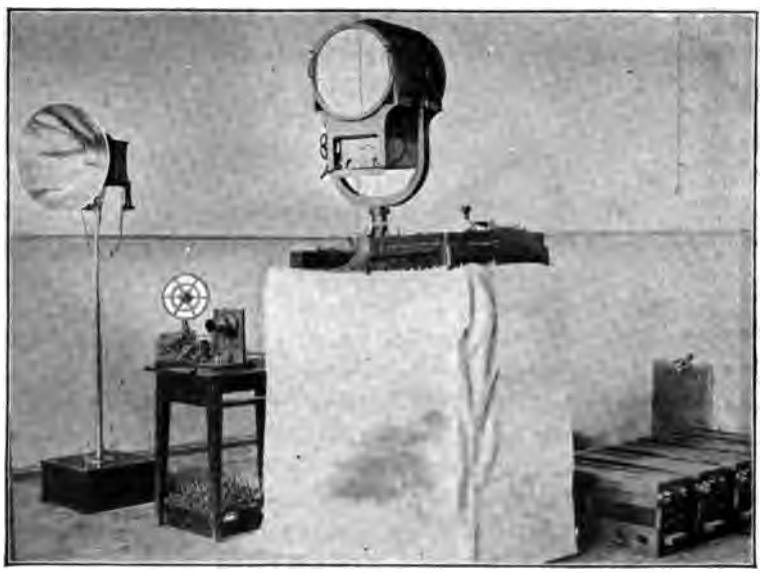


FIG. 16.—Ruhmer's Apparatus for Long Distance Telephony over a Beam of Light.

Mr. Ruhmer has conducted extensive experiments both by night and by day, and even during fog and rain on the Wannsee, near Berlin. On the screen you will see an illustration of his apparatus in actual work at night. (Fig. 17.)

Some time ago I suggested to Mr. Ruhmer the employment of Edison's tasimeter, the extraordinary sensitiveness of which is well known. He informed me that he had tried this; but had found it too " lazy "; and stated that he has secured most promising results by the employment of the thermopile; and with this he expects to be able to transmit sound over many miles.

Mr. Ruhmer is about to commence extensive experiments under the direction of the German Government in connection with the Imperial fleet in the Baltic Sea.

Mr. Ruhmer has also suggested the employment of his photographophone, which I shall describe later, as a means of recording messages received at a distance.

Doubtless many present remember the interesting experiments made by Mr. Hayes at the Electrical Exhibition held in Madison Square Garden in May, 1899, in which music was transmitted over a beam of light. At one end of the garden was placed a telephone, before which a cornet was played, causing waves of

FIG. 17.—Ruhmer's Wireless Telephone Receiving Station at Wannsee, Berlin (taken at night).

current in the telephone circuit to be superimposed upon those in a neighboring arc light circuit. The light rays from this arc lamp were reflected across the Garden, where they were received in a parabolic reflector in the focus of which was a glass bulb containing filiments of carbon. This bulb was connected to a pair of ordinary phonograph listening tubes. The varying light which fell upon the carbon caused variations of temperature inside of the glass bulb which produced the original sounds in the listener's ear. A bulb simply coated with lamp black and containing nothing but air, would answer the purpose just as well.

Selenium cells may vary in resistance from 2,000 ohms to 500,000 ohms or more in the dark; and certain cells may be five

to twenty times as good conductors of electricity in light as in the dark; and in the case of other cells, notably that of the Fritts' cell, which I have here this evening, and that of the Ruhmer cell used in his Wannsee experiments, will have two hundred times the conductivity in light that it has in the darkness; and the ratio may be even higher. They are usually made by winding carefully two separate lengths of wire, either of copper, brass, German silver or platinum, equidistant throughout their entire length upon such substances as slate, glass, mica or porcelain. The selenium is then spread thinly over the wires forming an insulation between the two windings. This form of cell was invented by Mr. Shelford Bidwell, F. R. S. . No small amount of skill is necessary to wind these fine wires evenly and equidistant, and to cover successfully these wires with the selenium coating. One way of coating frequently employed is to warm the cell on a metal plate or sand bath heated by a Bunsen burner. When the stick of selenium laid on the plate shows evidence of melting, which takes place at about 120° Centigrade, it is drawn slowly over the wires, coating the same thinly and evenly. A steel spatula or a strip of mica can be used with advantage.

Or the strip of material on which the wires have been wound would be laid upon a brass plate covered by a strip of this mica, this being placed upon a tripod with a Bunsen burner underneath. Powdered vitreous selenium may thus be spread evenly over the wires, and the selenium will shortly melt; and where the portions of it crystallize, forming hard lumps, it will be necessary to continue the heating until these disappear. Then the selenium may be spread uniformly with a piece of steel, or better still, a strip of mica, care being taken to cover up the edges. Mr. Bidwell states that the temperature should be carefully regulated, as when it is too low hard crystalline lumps will form, and when too high the surface tension causes the selenium to form in drops, and it is then as difficult to spread as if it were mercury. The proper temperature should be only just above 217° Centigrade; and then the selenium is in a plastic semi-fluid condition and can be easily manipulated. When a satisfactory surface is secured, the cell should be placed upon a thick copper plate to cool quickly, when the selenium becomes black and lustrous. The Bunsen flame should then be turned down to give a temperature of about 120°, and the cell is then placed upon the hot plate; and shortly, the whole surface of these turns to a dull gray color. The temperature is then cautiously raised until signs of melting begin to

appear, generally near one of the edges. When this occurs, the burner is instantly withdrawn and the flame lowered. The dark spot recrystallizes in the course of a few seconds, and the burner is then replaced and left for four or five hours, during which time the Se should be only a few degrees below the melting point. The coil should then be gradually cooled by lowering the flame gradually for an hour. This process of long heating and slow cooling is generally spoken of as " annealing."'

In Fig. 18 is shown an illustration of a number of types of selenium cells, including the Bidwell, Ruhmer, Giltay, Webb

FIG. 18.—Types of Selenium Cells.

Clausen & Bronck, Mercadier and Fritts, which I have brought with me for your consideration.

The two cells to the extreme right and left are modifications of Mr. Shelford Bidwell's cells, the original form of which consisted of two fine copper wires wound side by side on oblong strips of mica with melted selenium spread over the surface, the one to the left being manufactured by Ernest Ruhmer, of Berlin, and by Messrs. Clausen and Bronck, which consists of copper wire wound on slate. The one to the right is manufactured by Mr. J. W. Giltay of Delft, Holland, and consists of platinum wire wound on slate and covered with selenium. The four tiny cells shown against the white background are made by Mr. Hartwell W.

Webb, of New York City, and consist of German silver wire wound on slate. The cell to the right is placed in a sealed flat glass tube. The two lower Webb cells are incased in ebonite. The small round cell is a tiny Mercadier cell made by Mr. Webb. The method of making the Mercadier cell is to use two narrow ribbons of sheet brass or foil, separated by a ribbon of parchment paper rolled up like a spiral spring. This is held between wooden clamps, one surface being ground and polished off smoothly, and a thin layer of selenium being spread over it. An excellent idea of this cell may be had by noting Fig. 19, which shows the standard form.

In the center of the picture is shown a cell of Mr. C. E. Fritts, of New York City, for which I am indebted to my friend Prof. Geo. F. Barker. In the Fritts cell a very thin layer of selenium from one one-thousandth to one five-thousandth of an inch

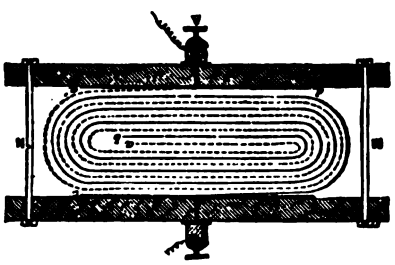


FIG. 19.—Mercadier's cell (block and dotted lines represent the two ribbons of brass).

in thickness is spread upon a plate of metal, generally zinc or brass. The selenium and metal plate form a chemical combination sufficient at least to cause the selenium to adhere and make good electrical connection. The upper surface of the selenium is then covered by a transparent conductor of electricity, preferably a thin film of gold leaf. Platinum or silver may also be employed. Thus the two surfaces of the selenium are covered by a metal and are connected to the two ends of the circuit. The upper or gold leaf surface, however, permits the light to pass through and affect the resistance of the selenium beneath.

The tall cell in the lamp socket shown is the latest form of Mr. Ruhmer's cell, and this type represents, I believe, the most important development which has been made in the selenium cell, and it has now become most stable and responds most rapidly to variations in illumination. He employs two copper wires,

wound spirally side by side around a cylinder of porcelain, which, after the wires have been covered with selenium, is placed inside of a globe, from which the air is exhausted and it is mounted with a butt similar to an Edison incandescent lamp, and resembles a candelabra lamp. This makes a most convenient method of handling the cell; and by keeping it from the air the disadvantages inherent in all cells heretofore have been very largely done away with.

Another form of Ruhmer cell consists of two fine platinum wires wound on a glass cylinder 1¼ inches long and ¾ of an inch in diameter; the wires which are 1/32 of an inch apart are coated with selenium.

Selenium cells are very susceptible to moisture, and it is largely this taking up of moisture which produces the electrolytic effect in the cell, enabling one to connect it with a galvanometer and produce a current by merely focusing the light upon the cell. This phenomenon gave rise to the designation of the photo-electric cell.

Those who have worked with selenium cells know that heretofore they have been most unreliable; varying their resistances from time to time enormously; and in the case where copper wires are employed, there is a selenide of copper formed, which often renders the cells inoperative in a comparatively short time.

To some extent, the cells made originally have been protected by covering them with mica or lacquer or varnish; but placing them in an exhausted receptacle and mounting them in the manner devised by Mr. Ruhmer is, it seems to the writer, a most important step in the commercial development of the selenium cell.

Prof. Bell has made a number of types of selenium cells, his standard form consisting of alternate disks of brass and mica, with the mica disks slightly smaller than the brass, forming a recess for holding the selenium, which is spread over the surface. All the evenly matched disks are connected to one end of the circuit; and all the old disks to the other end. The cylindrical form of the cell enables it to be acted upon from all directions, when placed lengthwise in the focus of a parabolic reflector. This is also of great advantage in the Ruhmer type of cell.

Selenium cells possess the remarkable property of recovering the original resistances upon the removal of the source of light.

It is well known that in the case of the radiophone, if a beam of sunlight be thus intercepted by a blackened perforated revolving

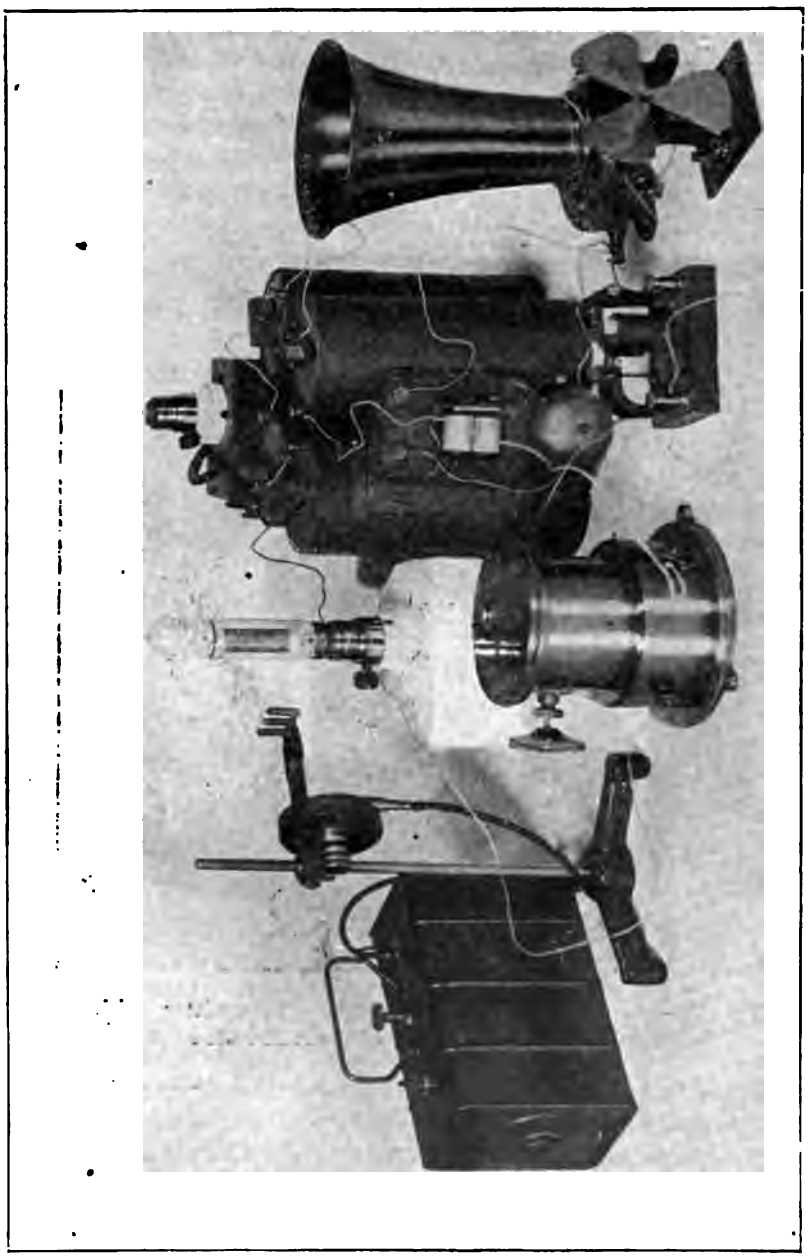


FIG. 21.—Acetylene Flame Apparatus, Ruhmer Selenium Cell, Relays and Battery for Operating Electric Lamp, Bell, Motor and Horn. (A 3 H.P. Motor and Generator were also similarly operated and a cannon fired.)

lecture, and shows in the foreground the three horse-power motor and generator which supplied a bank of lamps, and which plant was started and stopped many times when the author passed his hand between the acetylene flame and a selenium cell. The frontispiece is a general view of the stage setting in the College of the City of New York, and was taken shortly before Mr. Hammer's lecture.

In 1886 the writer attended a convention of the Edison Association of Illuminating Companies at Rochester, New York, and

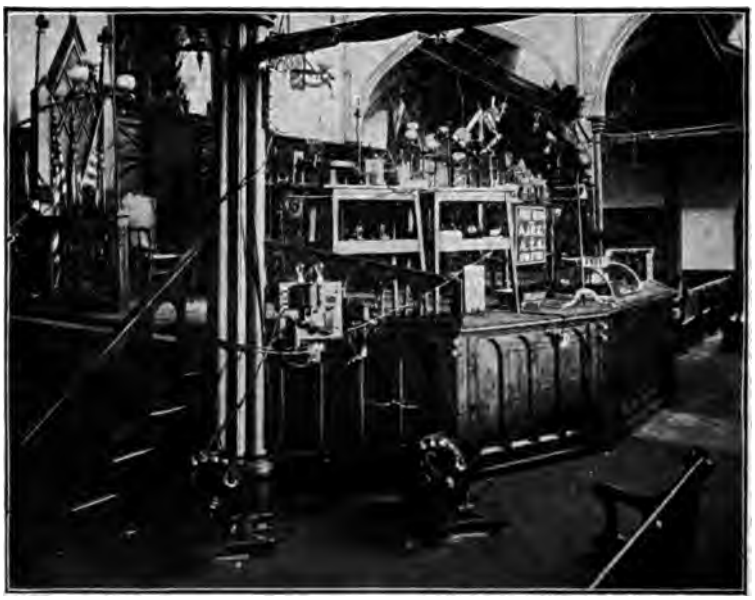


FIG. 22.—Three H. P. Motor and Generator supplying Bank of Lamps and operated by shielding with the hand a Selenium cell from an Acetylene Flame.

during a discussion of contract systems versus meter systems, he gave his experience as chief inspector of central stations of the Edison Company, in dealing with the difficulties met with in supplying light by contract; and he then described a practicable method of utilizing selenium cells to control relays and magnets which would throw off the electric lights on the approach of day and on again at night, thus solving the difficulty of street lighting, and other circuits intended to operate only at night.

On February 12, 1890, in a paper on some experiments with

selenium cells, Mr. Shelford Bidwell showed a relay operated by a selenium cell, which threw on an electric lamp and rang a bell; and he suggested the protection of safes and strong rooms by selenium cells, which would be affected by the light from a burglar's lantern, thus giving an alarm. He also spoke of their being used to give notice of the extinction of railway signal lamps and ship lights, and stated the following: " But I do not at present attach any serious importance to such practical applications of these devices. I regard them simply as offering somewhat attractive illustrations of the effect of light upon the resistance of selenium."

This is an important statement from the greatest authority on the subject of selenium, but to-day it will not hold good.

I hold in my hand a small vial containing some " thermit," which was discovered by Dr. Goldschmidt. It consists of oxide of iron, such as one would get off of a blacksmith's anvil, or from the rolls of a rolling mill, and is mixed with powdered metallic aluminum. A red hot iron or molten cast iron poured into this mixture produces no effect; but if a little barium preparation or magnesium powder be placed on top of this mixture and touched off by a match, an extraordinary reaction takes place, producing a temperature of about 3000° C., and the mechanical equivalent of a kilo (2.2 lbs.) of thermit is about 1,730 horsepower seconds or 1,273 kilowatt seconds.

I have seen some very interesting experiments made in welding girder rails, pipes, etc., by this process, and have here some interesting samples of manganese, chromium, ferro-titanium and other metals prepared in this way.

I have also seen steel safes in which enormous holes had been burned by employing thermit; and it would be possible for a burglar to carry some thermit in his pocket and burn a hole in a safe large enough to insert his arm and extract the valuables.

I also saw in Germany last summer a substance called " antithermit," which it is intended to place in the lining of safes to prevent the reaction taking place, thus protecting the safe. But a simple plan would be to place a selenium cell in or near the safe, so that the moment the reaction was started, a signal would be given to the police in a similar manner, as suggested by Mr. Bidwell in the case of the burglar's bull's-eye lantern.

An important commercial application of the selenium cell has recently been made by Mr. Ernest Ruhmer in connection with his electrically controlled buoy illustrated in Fig. 23.

Pintsch has constructed a large number of buoys containing compressed gas, which would last from one month to upwards of a year; but it was heretofore necessary to burn these lights day and night, it being often impracticable by reason of distance at which they were placed, and frequency of storms, etc., to switch off the gas so that it would not burn during the day time.

Mr. Ruhmer has placed one of his selenium cells in the top of such a buoy connected with a switching device which, as soon as the sun rises in the morning, causes the selenium cell to reduce its resistance, this causing the switching device to turn off the gas, which is again turned on upon the

FIG. 23.—Pintsch Gas Buoy Controlled by a Ruhmer Selenium Cell, Battery and Switch Mechanism.

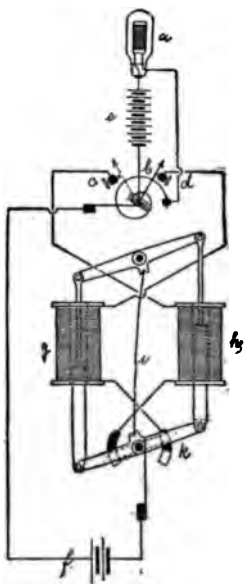


FIG. 24.—Diagram of Circuits of "Selenium" Buoy.

increase of resistance of the selenium cell by the approach of night-fall, or if desired in the case of a storm coming up. A buoy containing sufficient gas for one month could thus be made to answer without recharge for from three to five months.

The arrangements of the circuits as originally devised by Mr. Ruhmer is shown in Fig. 24. The voltmeter needle has been replaced by a relay, and the apparatus simplified. A single dry cell is interpolated in the selenium cell circuit, as usually employed on the buoy; and this cell will last a year or more; and with the relay, it is placed in the bottom of the buoy and arranged to be absolutely waterproof.

When I was in Berlin last August, one of these buoys had been in operation since the previous October, turning the light on and off every night and morning; and Mr. Ruhmer has recently written me that it is still operating successfully, as are others which he has placed near Hamburg and in the Baltic Sea.

Mr. Ruhmer has also constructed an apparatus employing the selenium cell to which he has given the name " photographophone," which is one of the most remarkable pieces of scientific apparatus that it has ever been my pleasure to see. Figs. 25, 26

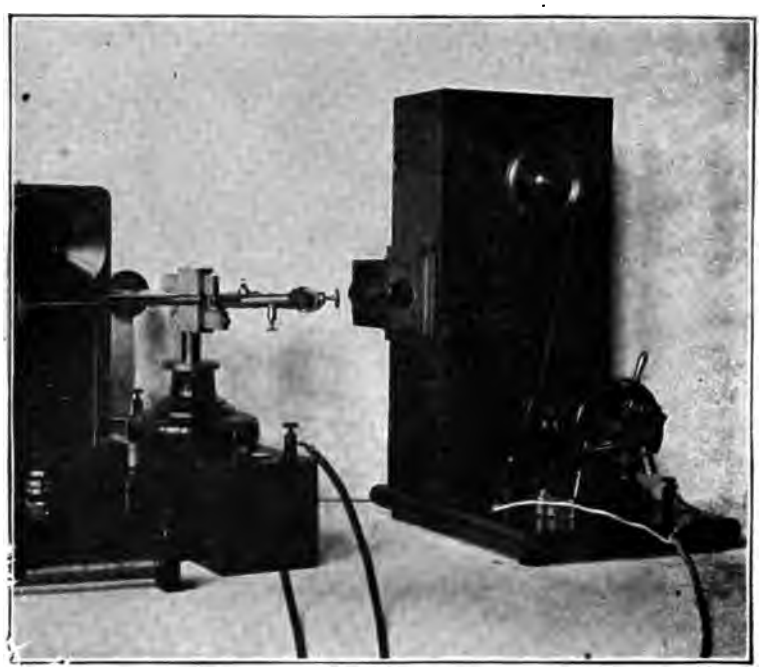


FIG 25.—Ernest Ruhmer's Photographophone, Showing Exterior View, together with Telephone Transmitter and Arc Lamp.

and 27 illustrate the general construction of the apparatus, which I shall further illustrate by accompanying lantern slides. In Fig. 28 the apparatus is shown diagramatically and in Fig. 27 the inventor is shown listening to the photographophone reproducing speech and music. It consists of a box containing a gelatine or celluloid film, such as employed in moving picture machines, which is driven at high speed by means of an electric motor. In the front face of the box is set a cylindrical lens about the size of one's little finger. A short

distance away from the box is placed an arc lamp and a telephone. Words spoken or sung into the telephone superimpose the waves in the telephone circuit upon the current flowing in the arc light circuit, and cause a corresponding variation in the light of the arc. The rays from the arc lamp pass through the cylindrical lens already referred to, and are caused to fall in sharp white lines on the moving sensitive film. This film, upon being taken out of the box and developed, shows a series of perpendicular striations parallel to one another, which are really a photographic record of the sound waves originally entering the telephone transmitter. Where the striations are fine and close together, the pitch is high, but where they are broader and farther apart the pitch is low. Strips of the films or photograms are shown in Fig. 29. The developed film is next placed back into the box and the motor again started. The arc lamp remains in its original position, but

FIG. 26.—Showing Interior of Ruhmer's Photographophone.

burns steadily as the telephone is not operated. The rays from the arc lamp passing through the lens are therefore quite uniform, and the moving gelatine strip acts as a screen to cut off these rays, allowing the light intermittently to fall upon the selenium cell at the back of the box, producing a variation in its resistance and a corresponding effect in the telephone receivers connected thereto. A battery is also interpolated in the circuit with the selenium cells and the telephones. By holding these telephones to the ear, the reproduction of the sound is perfect, as I can vouch for from personal experience with the apparatus.

Mr. Ruhmer contemplates utilizing this photographophone as a receiving instrument with its wireless telephone system, in which he employs a beam of light, as already described.

Mr. Shelford Bidwell has also made a device for producing pictures or writing at a distance by combining the properties of selenium with the chemical telegraph.

Various inventors have endeavored to solve the problem of seeing what goes on at a distance by employing selenuim. Among these are Perosino, Senlecq, de Paioa, Cary, Sawyer, Larroque, Nipkow, Gemmill, Liesegang, Heinzerling, Edison, Stern, Jan Szczepanik, Dussaud, Otto von Bronk, von St. Schneider, Ayrton and Perry, Korn, and others, who have proposed various methods employing images thrown on ground glass or through a photograph negative, or upon mirrors swinging synchronously, by or

FIG. 27.—Mr. Ernest Ruhmer Listening to his Photographophone.

using revolving perforated screens, for cutting off the beams of light, multiple selenium cells which would be affected by high lights and low lights of the original picture, etc., these devices affecting some method of illumination at the receiving end or producing an electrochemical action such as is produced by the usual chemical telegraph systems, or controlling an electropantograph system such as Gray's telautograph. These various inventions have been termed the telescope, telephote, telectroscope and the telephotograph. But these devices have thus far reached little further than descriptive matter, drawings and crude experiments.

Various people have suggested the use of selenium cells for photometric purposes; and it is interesting to note that Mr.

Latimer Clark suggested this application the evening in which Mr. Willoughby-Smith first brought to public notice the phenomena of variation in resistance of selenium when exposed to light, to which I have already referred.

Mr. Fritts has suggested making a form of photomoter which would be sensitive to lights of different color, as well as of varying candle power, by employing as a film on the surface of his cell a gold foil which transmits green rays, a silver foil the blue rays, and so on; and suggests that a solid transparent conducting film which would transmit all of the rays would be far better and thus remove the color stumbling block in photometric work.

Sir William Crookes has constructed an exceedingly interesting type of radiometer, in which he has coated the revolving vanes on one side with selenium, and on the other with chromic acid. He

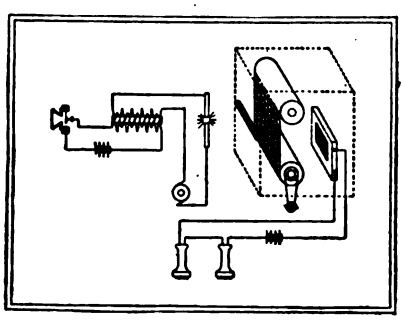


FIG. 28.—Showing General Arrangement of Circuits of Ruhmer's Photographophone.

found that the white light from a sperm candle repelled the selenium, while the yellower light of the wax candle repelled the chrome, thus indicating the relative absorptive powers of the different substances for rays of different refrangibility, resulting in mechanical motion; just as the same selective capacity operates in photography as chemical action.

In 1891 Prof. Barnard of Lick Observatory employed a selenium cell as a device for automatically detecting comets, and Minchin has employed the selenium cell quite extensively in his astronomical investigations.

In Fig. 30 is shown a curve which Mr. Ruhmer recently sent me which shows some observations made by means of his selenium cell during an eclipse, these being the only observations which anyone was enabled to make at that time, on account of stormy weather. Mr. Ruhmer has prepared an interesting paper bearing on this and other applications of the selenium cell to meteorology. He made his observations on October 31, 1902.

Selenium is found in Vesuvian lava, and in natural sulphur as a sulphur selenide in the Lispari Islands. It is also found in Norway and other iron pyrites. It occurs in meteoric iron and in such rare metals as eucarite as a selenide of silver and copper in Sweden and Chili; crooksite, a selenide of copper and thallium with a little silver, from Norway; as clausthalite, a selenide of lead in the Hartz Mountains, from Zinken and Clausthal, in Inverg, Rheinberg, Saxony, Rio Tinto, Spain, Mendoza, South America; as riolite at Culebras, Mexico; as Lehrbachite, a

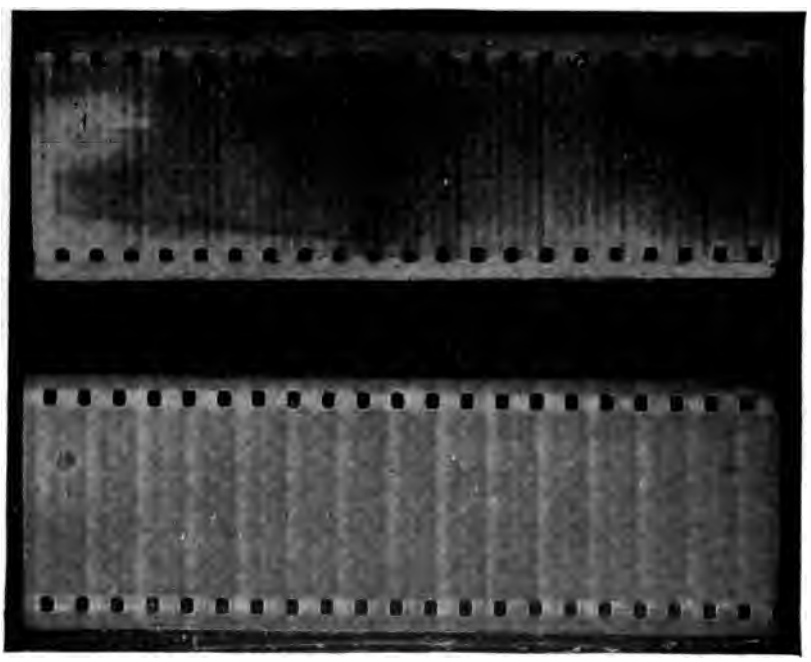


FIG. 29.—Photogram as used in Ruhmer's Photographophone (High Pitch Tones above, Low Pitch below).

selenide of mercury and lead from the Hartz Mountains; as zorgite, a selenide of copper and lead from Glasbach in the Hartz Mountains. Selenium, although widely distributed over the globe, occurs only in small quantities and in some instances is found in native state.

Selenium is placed among the rare metals. Chemically pure crystalline selenium costs about $1.00 per gramme; and the ordinary commercial article about 10 cents per gramme

The Bibliography of selenium is quite extensive. Those interested in the subject will find an excellent paper by Mr. A. P. Saunders

in the *Jour. of Chem.* for June, 1900. The paper contains many references, and is entitled " Allotropic Forms of Selenium."

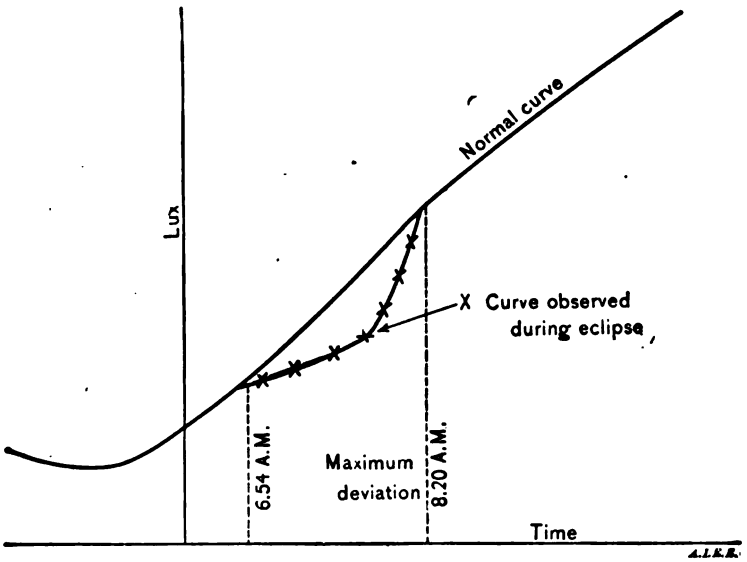


FIG. 30.—Curve Taken with Ruhmer Cell During Eclipse, Oct. 31, 1902

THE TREATMENT OF DISEASE BY ULTRA-VIOLET RAYS

PROF. NIELS R. FINSEN.

Some professional matters detained the writer in Copenhagen last summer for several weeks, and during his stay in that city he had the privilege of visiting the Finsen Light Institute at Rosenvaengat, a suburb of Copenhagen, and was enabled to investigate the system for the treatment of disease by light, inaugurated by Dr. Niels R. Finsen. In Figs. 31 and 32, are shown views of the operating room at the Finsen Institute, where a large number of patients from various parts of Europe were undergoing treatment at the time of my visit.

Dr. Finsen has conducted very extensive and most painstaking

researches into the bacteriacidal effects of light, and he has found the violet end of the spectrum to possess remarkable curative powers, and he has also found that by utilizing the blue, violet and ultra-violet rays of the spectrum, those loathsome diseases of tuberculosis of the skin and lupus, diseases which have baffled surgical skill heretofore, have been successfully combatted.

It has recently been stated that in New York City alone there are annually 20,000 cases of tuberculosis, with 8,000 deaths; and there is probably no disease with which mankind is afflicted which compares in deadly character to tuberculosis.

In affecting certain of the internal organs, it is known as consumption, and appearing externally, attacking the skin and underlying tissues, it is known as lupus vulgaris. As a rule, it appears in single patches, most frequently attacking the face, especially the nose, cheek and mouth. It may, however, attack the extremities or, in fact, any portion of the body and even mucus membranes. Fortunately, lupus is rather rare in this country, although very common in Europe.

Koch and others have fully demonstrated that tuberculosis is due to the presence of specific organisms named " tubercle bacillus," which have been found to be present in both the internal and cutaneous forms of the disease.

Doubtless many present remember the " blue glass craze," which swept over the country in 1876, or thereabouts.

I have with me here a copy of General A. J. Pleasonton's book entitled, " Blue and Sunlights, Their Influence upon Life and Disease," which I picked up in a second-hand book store some years ago; and I would commend the examination of this book to all who are interested in the subject. General Pleasonton and his system were condemned to both abuse and ridicule. Dr. Finsen, however, says, " The General was absolutely on the right track."

For a considerable time Finsen's work received little credence and no encouragement; but he persisted in his investigations, and the results secured by him finally bore fruit, and to-day the world rings with his praises. In all parts of the civilized world his work is being taken up, and institutes are being founded for the treatment of disease by light rays—particularly the ultra-violet light. In England the initiative was taken by Queen Alexandra, and in Russia by her sister, the Czarina, they both investigating the system while visiting their father, the King of

FIG. 31.—Showing Main Operating Room, Finsen Institute, Copenhagen.

FIG. 32.—Showing Arc Lamp and Four FinsenTubes in Use at One Time.

Denmark. Much has also already been done in the United States.

It will be remembered that during Queen Elizabeth's reign a certain court physician recommended strongly that patients suffering from small-pox should be kept in a room, the decorations of which, including the hangings, bed draperies, etc., should be red in color, claiming that the red light had a soothing effect upon the irritated portions of the skin, lessening the severity of the disease. Little importance was attached to this method, and the originator of it was branded as a Charlatan.

Prof. Finsen, has, however, found that this method of treatment of small-pox is of paramount importance. He has placed patients in a room into which the sun's rays could only penetrate through sheets of red glass, just as they would penetrate a photographic dark room; and he has found that patients placed in such a room prior to the most painful and most dangerous suppuration stage setting in, that suppuration has been entirely prevented and that the scarring has been in nearly all cases absolutely prevented, and in the few cases where there was any scarring, it was hardly perceptible. The disease has been in a much milder form, the fever usually accompanying the eruption disappearing, and the temperature remaining normal.*

He has found that the use of ultra-violet light on these patients very much aggravated the disease, and even in cases where patients were almost cured and they have been allowed to go out into the sunlight, the disease has at once been aggravated.

In connection with his investigations into the effects of light Finsen made some interesting and ingenious experiments upon earth-worms placed in a box, one-half of which was covered with red glass and the other half blue glass; and he found the blue light irritated the worms so they invariably crawled under the red glass, and a chameleon, placed with its body midway between the glasses, turned almost jet black under the influence of the blue rays, while that portion under the red glass remained nearly white, which Prof. Finsen says showed that the chameleon was altering its pigment cells to lessen the irritating effects of the blue light.

The ultra-violet end of the spectrum contains the most refrangible rays, and it is these rays which are so harmful in cases of smallpox; and it is also these actinic rays which produce sun-

* Prof. Finsen has recently written the author that placing the patients in a dark room is fully as efficacious as placing them in a room lighted with red rays only, the important thing being to keep the patient from exposure to the actinic rays.

burning, which one often experiences in the Alps, or any high altitude where the temperature may be considerably below zero; and there are doubtless many present who have experienced considerable effect similar to sunburning by working in close proximity to arc lamps.

While these ultra-violet rays are so harmful in the case of smallpox, they are of the precise nature which is most desirable in the treatment of such diseases as tuberculosis of the skin or lupus vulgaris. These rays not only destroy the bacilli, but they excite and stimulate nutrition and excite activity in granulation, thus assisting very greatly in the rapid recovery from the disease.

Doubtless the rays emanating from the sun are very rich in blue, violet and ultra-violet light; but the atmosphere readily absorbs these rays, and while Prof. Finsen for a time used the sun's rays in the treatment of tuberculosis of the skin and lupus he found that by employing the arç light the same effect could be produced in a very much shorter space of time; and that he was in this way, also, independent of weather conditions.

The arc light is much richer in ultra-violet rays than the sunlight; and Broca and Chatin of Paris have found that by placing an iron core inside of the positive carbon electrode, this arc was still richer in ultra-violet light, and Görl of Erlangen, has constructed a form of aluminum arc, in which four arcs were formed between five aluminum electrodes. I have here a modification of Görl's lamps constructed by Messrs. Waite & Bartlett of this city, in which there are four iron electrodes forming three iron arcs in series, which produce an intense source of ultra-violet light, which I shall presently show in operation.

Bang and others have also made arc lamps employing terminals of iron.

It is claimed that by employing the iron arc the same results which take an hour and ten minutes by means of the carbon arc can be accomplished in twenty minutes to half an hour; and also that so intense are these ultra-violet rays it is not necessary to use pressure to drive the blood away from the diseased part, and it is also unnecessary to use water to cool the rays.*

Drs. Piffard and Jamieson have suggested the use of suprarenal extract in the form of adrenalin chloride, which the former prefers to introduce into the skin around the diseased spot

* Prof. Finsen has recently written the author emphatically asserting that iron electrodes are not as efficacious as carbon electrodes as the rays from the iron arc, he claims, do not penetrate as deeply as the rays from the carbon arc.

by cataphorisis, thus producing a whitened area from which the blood has been withdrawn, which enables the treatment of this portion by the ultra-violet light, without pressure being applied, and the blood does not return for half an hour or more. The cataphoric electrode is covered with a thickness of lentine saturated with adrenalin connected with a positive pole of the battery, using a current of from three to four milli-amperes, the bleaching taking from four to five minutes' time.

The Roentgen rays have been found very effective in the treatment of certain diseases, especially where hard tubes are employed, and as we are considering particularly the treatment of lupus vulgaris, I would call attention to Fig. 33, which repre-

FIG. 33.—Lupus Vulgaris Cured by X-rays.

sents a patient treated by my friend, Dr. William H. King of this city, in which the X-Rays successfully cured a case of lupus vulgaris brought on by the patient's pricking a tiny boil on the side of his nose with a pin taken from the lapel of the coat of a friend who was suffering from tuberculosis (consumption). The rapid progress of the disease is shown in the illustration and was taken three weeks after using the pin, and was largely augmented by the man's age (45), and his being in poor health (a chronic rheumatic). Two bacterialogical examinations showed conclusive evidence of the presence of tubercle bacilli.

In Fig. 34 is shown the original blue lens used by Finsen when employing sunlight. It consists of a flask full of light blue ammoniacal sulphate of copper. The bottle with its contents

makes a plano-convex lens. The sunlight passing through this is found to work very well; but it was too slow, and the sun was frequently obscured. Finsen later used plain water, finding that the blue water cut off most of the ultra-violet rays and he found the clear water very largely absorbed the ultra-red rays which caused the heat.

In Fig. 35 is shown a form of telescope which is now adapted in standard practice at the Finsen Institute. It contains four rock crystal lenses, which act to cut off considerable of the heat rays but allows the ultra-violet light to pass through it.

FIG. 34.—Finsen's Original Blue Lens for Use with Sunlight.

It will be remembered that ordinary glass cuts off almost all of the ultra-violet rays, whereas a block of rock crystal 4.4 mm. thick will allow 60 per cent. of the ultra-violet to pass through it.

A part of the heat is also absorbed by the distilled water which is contained inside of the telescope. In order to keep this water cool, there is an outside jacket on the telescope, through which circulating water may be passed for this purpose. In Fig. 36 is shown the method of arrangement of the telescope and the arc lamp; and in Fig. 32 is shown a set of four of these telescopes arranged around the arc lamp and in actual operation. The arc lamp uses from 40 to 80 amperes and operates at 45 to 50 volts.

Blood is opaque to ultra-violet light, and it is therefore necessary to drive the blood away from the diseased portion which is to be treated. This is accomplished by what is known as a pressure glass shown in Fig. 37. It consists of a plano-convex lens of rock crystal kept cool by circulating water—the glass acting to focus the light on the diseased portion, and also to exert considerable pressure there.

The patient does not suffer from exposure to the rays; but after the treatment, which is usually an hour and ten minutes per day, he appears to be considerably sunburned. He is then allowed to recuperate until the next day, and the treatment is then repeated. After a series of these treatments, the patient is sent away apparently cured. Sometimes he does not return; but more often he must come back for a second or third, and even more series of treatments, due to the fact that certain of the

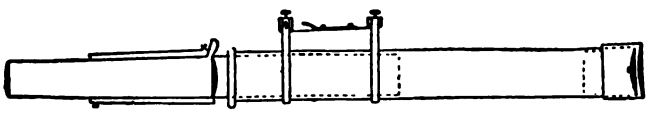


FIG. 35.—Finsen Telescope Tube, for Use with Carbon Arc Light.

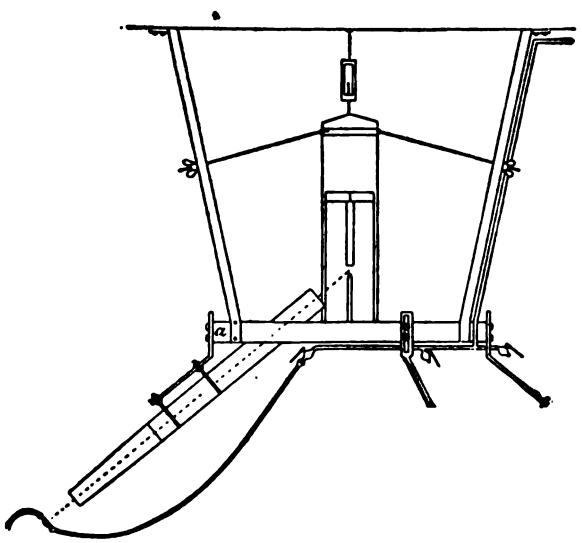


FIG. 36.—Showing Arrangement of Arc Lamp and Finsen Tubes.

microbes which have been deep-seated have worked their way to the surface, the disease having started anew.

It is said that out of over 600 cases treated at Copenhagen, there have been only 1 to 2% of failures due to fault in the treatment; but there have been cases where the disease has been in such an advanced stage and for such a very long period that it has not yielded successfully. But I was informed that in the majority of cases after very few treatments, the patients are dismissed absolutely cured. In order that you may properly

FIG. 38.—Showing Lupus Vulgaris Patients Before and After Treatment with Ultra Violet Light at the Finsen Institute, Copenhagen.

appreciate the remarkable results which have been secured by Prof. Finsen; and the stupendous importance which his successful combatting of these loathsome forms of disease represents to many of the most sorely afflicted people of this world, I have inserted in my paper several photographs, see Fig. 38, which I secured at the Finsen Institute; of patients afflicted with lupus vulgaris—these pictures showing them before and after the treatment with the ultra-violet rays produced by the arc light I feel that their presentation in this paper requires no apology, on the contrary, electrical engineers should feel a sense of pride that in the use of the arc light in this remarkable advance in medicine and surgery, their profession has contributed in no small degree.

Those caring to look up these and similar cases, will find full descriptions in English in " Phototherapy after Finsen's Methods," by Valdemar Bie, M.D., Prof. Finsen's Assistant (published

FIG. 37.—Pressure Lens.

by Lippincott), or Die Bekampfung des Lupus Vulgaris von Niels R. Finsen (Gustav Fischer Jena), and Die Finsen Therapie und ihr gegenwartigen stand in des Dermatolo-gie, von Dr. Forchhammer 1. Cohen's Buchdruckereien Kopenhagen).

The little cut of Prof. Finsen which heads this article is from an autograph portrait which Prof. Finsen presented to the writer, and it is sad to contemplate that this man who has conferred such a priceless boon upon humanity is himself an invalid, suffering from an incurable disease, and one which has made it at times well nigh impossible for him to prosecute his work.

The Finsen Institute was established in 1896, through the munificence of Copenhagen's public-spirited citizens, and through a gift by the city of the property on which it was erected.

The lecturer desires to express his appreciation of the services rendered by his assistants, Messrs. Varley, Lawton, Brown, Webb, Scheerer and Dow, and also to acknowledge the courtesies extended by the New York Edison Co.

A paper read at the 176th meeting of the American Institute of Electrical Engineers New York, April 24th, 1903.

TENDENCIES OF CENTRAL STATION DEVELOPMENT.

Introduction by President Scott.

If we were to go back to its very beginning, we should probably find that there were two elements which marked the dawn of civilized life, and which may be traced through all its development. One of these was the use of implements—probably a club and a sharp stone were the earliest tools. The other was coöperation for a common purpose—probably protection against a common enemy was the first incentive.

These two elements: namely, the use of tools, or more particularly the adaptation of the materials and forces of nature to accomplish results beyond the power of the individual; second, coöperation followed by specialization, in which individuals of different abilities act together, each one doing the share for which he is best qualified, may be traced through the various stages of development, prehistoric, ancient, and modern. The development along these lines has been especially marked during the past century and notably the past generation. The interrelation between these two elements is notable. The use of tools and of machinery, together with the generation and the application of mechanical power have brought about a new order of things in the relations between individuals and the relations between nations. Manufacture and commerce have passed through a wonderful evolution. Social conditions have changed. The whole United States is scarcely larger as measured by the time-table for travel or the rates for transportation of freight than was the little island of England a century ago. In the time of Dr. Johnson the mind of one man was presumed to be able to encompass the whole of human learning. The change which has taken place in learning is indicative of the broadening and the special-

izing which characterizes every department of modern life—intellectual, industrial, commercial, social.

Society is not a mere aggregation of individuals; it is not simply a mass of men, but it is a vast unit. Men are not independent; they are correlated and interdependent. The fundamental condition for such a state is material. Just as a factory is essential for workmen who are to build dynamos or locomotives, so do the material facilities of our modern cities—their buildings, their street cars and elevators, their telephones, their water supply and sewage systems, their lighting and power systems—constitute the factory, the tools, the mechanism which makes our modern life larger and more effective than that of the olden time.

I think of no institution which is so completely representative of the modern development of those early beginnings of civilization whose development we have been tracing, than is found in the Central Station. In it is found an application of natural forces on a most comprehensive and diversified scale. Its very existence is dependent upon social coöperation; and in turn it contributes to the convenience and the comfort and the effectiveness of a whole community.

Electricity is a unifying agent. As a science its theory promises to be the secret which will bring together the mysteries of chemical affinity, of magnetism, of light, of gravitation. As an engineering force it is on most intimate terms with every branch of engineering, aiding, unifying and simplifying. I repeat an illustration which I once used before the INSTITUTE:

> 'A generation ago it would have defied the imagination to discover any natural connection between such widely different agents as horses pulling street cars, locomotives drawing elevated trains, gas lighting houses and streets, water operating elevators, stoves heating and cooking, and engines of every sort and class doing a hundred kinds of work. But all of these and many others are in common being superseded by the electric current, which does not merely replace but develops, expands and transforms. It is notable that all of this varied service . . . could be supplied with current from a common universal system."

The Central Station system in itself is typically representative of coöperation and combination in design and construction, in the combustion of coal and the production of steam, the operation of engines and condensers, of dynamos and switches, of indi-

cating instruments and safety devices, of conductors and cables, and the operation of apparatus in substations and on the premises of a thousand customers. Each element is in a measure dependent upon all the others. The reliability of the Central Station commends in highest terms the ability and success of the modern engineer.

The following statement has been given me to-day: "The Edison system in New York City as a whole has never been without current. There have been several accidents, including the fire at the old Pearl street station in 1890, which have temporarily affected a district, but since 1893 there have been no interruptions of service on the system. On March 31, 1903, the New York Edison Company, on Manhattan Island, was supplying current to 26,000 customers a total equivalent in 16-candle power lamps of 2,391,431."

The Central Station system is an evolution—an evolution as a whole—an evolution in its elements. In 15 or 20 years many of its elements have come into existence, while others have undergone most radical changes—boilers, engines, generators, switchboards, cables, safety devices, rotary converters, lamps and motors—and in addition to the apparatus there has been the growth of the great system by which they constitute a single whole.

Progress has not ceased—its acceleration continues. The Central station will in itself increase its extent and its effectiveness. As electric power distribution in the factory has revolutionized methods and led to increased output and reduced cost of products, so electric power distribution in the city revolutionizes the customs of the people, and is a vital factor in advancing civilization.

A paper read at the 176th Meeting of the American Institute of Electrical Engineers, New York, April 24, 1903.

ECONOMICAL AND SAFE LIMITS IN THE SIZE OF CENTRAL STATIONS.

BY H. A. LARDNER.

Some of the considerations which induce companies to erect large central stations. The probable effect of steam turbine development on the size of generating units. Advantages and disadvantages of large central stations. Where several small stations replace one large plant the necessity for excessive engineering refinement ceases to exist.

In this day of gigantic engineering enterprises, one would be very conservative indeed if he placed any limit on the possible size of modern central stations. From the plans for extending some of the well-known plants, the engineers of the companies owning them apparently think they have not reached the limit either from the point of economy or of safety. I shall certainly not attempt to place any limits on the size of power stations, for each case must naturally be considered as a separate problem. However, I may call to your attention some of the considerations which induce companies to erect large stations, and give an opinion of the objections and disadvantages which attend their operation. There are many subjects which have an important bearing on the question and some of them will be discussed.

TERRITORY TO BE SERVED.

If the territory is large and the system is to serve several villages or small cities with power for lighting or for railway purposes, one large station located conveniently for coal and water has a decided advantage, owing to economy in labor, lower cost of fuel, water and first cost.

Frequently the business in the individual towns would not be large enough to permit of an independent plant in each, and any risk of interruption to service is put up with because it is the best kind of service that such a community can support.

In fact, until the class of territory approaches that of our largest cities, the question of lower first cost and economy of operation must in general rule; for the size of station is not large enough to minimize those advantages or to demand the advantages of a service supplied by several stations, harmoniously designed and operated.

When the territory becomes similar to New York, Chicago, Brooklyn, Boston, etc., the large station has many claims for consideration. As the central stations now built in this class of territory are so much larger than those which have been erected elsewhere, we may confine our discussion to stations for the larger cities.

We may also exclude water power stations, as they must of necessity be located at the point of development or waterfall, and it is seldom the case that several plants can be built, each large enough to secure the maximum advantages of low cost and low operating expenses, as at Niagara.

System of Distribution.

The system of distribution which must be used, frequently has a direct bearing on the demand for a large station. Where the distribution pressure is low as in Edison three-wire 120-240 volt systems, there are few if any cities where a sufficient load can be found for a very large station without exceeding the limited zone of economical distribution at this pressure.

Where this system is in operation we find that the stations are generally of high first cost and too small to be operated economically. The location is necessarily chosen without regard to the water or coal supply, and the load factor is generally very bad, which adds to the expense of operation. As a temporary expedient at least, rotary converters, transformers and high pressure cables have found a place for connecting together the direct current stations and thus enabling them to exchange power and considerably improve their load factors.

For instance, in New York City the Duane Street Station of the New York Edison Company, with its heavy day load of motors and early evening load of office buildings, has a very different shaped load curve from the 26th Street station or the generating stations formerly located in 39th Street and 53d Street, which

delivered their principal service during the evening. However, the double conversion results in losses which should be saved, and still continues the use of uneconomical small stations.

The next step is to establish a large well-located alternating current station and feed the rotaries from the machines there installed. This method permits the use of the largest size of generating units, gives their attendant economies, and the demands of the various sections of a city coming at different hours of the day produces a better load factor.

The generating apparatus installed in the distributing or substations, as they may now be called, can be operated if desirable for one or two watches during the heaviest loads in their particular sections, and the combination undoubtedly results in greater economy. The existence of these substations with generating apparatus provides a certain amount of reserve or emergency power which can be called upon, and the danger of concentrating all the generating apparatus in one station is in a measure avoided. The fact of their existence also acts as an incentive to keep down the number of new generating stations and to build one alternating station large enough to meet the entire demands of the system, no matter how large that may be.

The use of the 240 volt incandescent lamp is much more common abroad than with us, and while I am not able to comment on the relative merits of the lamps made at home and abroad I do believe that a more insistant demand for a 240 volt lamp would be met by our manufacturers and result advantageously.

By the use of a three-wire system and 240 volt lamps, the advantages of 500 volt distribution in copper economy can be obtained, and the zones which can be served from any one station very considerably increased. It is an open question whether with this system of distribution the stations can be made large enough to be built for a fairly low first cost and operated at practically a minimum expense. There is a case in point in Boston, where the Boston Elevated Railway Company has a number of stations ranging from 1,500 to 4,000 k.w. and the results of operation are reported to be very low and comparable to the best results which have been shown in much larger stations.

The alternating current system of distribution with primary voltage of 2,200 volts and over, has the ability to serve a very extended territory. With this system of distribution, the question of one large station should not be so important, as the load can probably be divided between two or three stations, each

large enough to be economical, and by the use of trunk cables they may aid one another in handling the load and add materially to the safety and continuity of the service.

SIZE OF UNIT FOR MOST ECONOMICAL OPERATION AND FLOOR SPACE.

From the compilation of Mr. C. D. Gray in the Journal of the Franklin Institute, October, 1901, I give the results of tests on compound Corliss condensing engines. The best results published, and one near the average, are given for several different sizes.

Pressure.	Vac.	I.H.P.	Steam.	Authority.
155		1950	12.5	Thurston; *Science*, Oct. 1, 1897.
150	26.9	1713	12.3	Barrus; " Engine Tests."
123	25.6	1592	13.5	Thurston; A. S. M. E., 15–839.
133	25.2	1539	14.1	Barrus; " Engine Tests."
126	27.0	1107	14.1	Barrus; " Engine Tests."
120		1018	13.3	Barrus; A. S. M. E., 15–839.
117		1001	16.3	Sibley Journal, 8–393.
151		997	12.8	Barrus; A. S. M. E., 14–1340.
112		709	15.1	Stone & Webster; *S.R.J.*, Aug., 1898.
144	25.2	741	13.2	Barrus; " Engine Tests."
159	25.4	595	12.7	Dean; A. S. M. E., 16–169.
90		548	13.5	Thurston; *Elect. World*, Jan. 5, 1901

It will thus be seen that under proper conditions of design and operation, very good comparative results can be secured with units much smaller than those installed in the large stations in New York.

The published guarantees for the steam consumption are as follows, in these stations:

Station.	Pressure	Vac.	I.H.P.	Steam
The New York Edison.....	175	27	5500	12.5
Manhattan Railway	150	26	8000	13.0
Metropolitan Street Railway	160		4500	13.14

That part of the cost of labor for engine operation, which varies with the size, amounts to but a small portion of the total operating expenses; and although the larger the unit, the smaller the item becomes per h.p. hour, it is relatively of little importance, except in very small units.

The question of floor space required for reciprocating engines of different sizes demands the largest units practicable.

The vertical space required by an engine is provided more cheaply than the floor space, and as the requirements are of three dimensions the floor area should not increase proportionally

with the size of the unit. Again, the aisle space must be practically the same for engines differing in size by large percentages.

In spite of these facts; the floor space in engine rooms per h.p. appears to be affected more by the type of engine used and the judgment of the designer than by the size of the unit. The Edison station, with engines of 5,500 h.p. normal rating, requires only about one-third of a square foot per h.p. and the Metropolitan, with 4,500 h.p. units, one-half of a square foot per h.p. against the 8,000 h.p. units in the Manhattan station, with an area of .55 of a square foot per h.p.

It therefore appears that economy of operation and in floor space may be made entirely too much of in discussing the advantages of large units, although with similar design and type of machinery the large units undoubtedly have some advantages, provided the station is large enough to require a sufficient number of units to permit of economical loading.

The following table will give some published data about the engines in the New York Edison, Manhattan Railway and Metropolitan stations:

Engines.	Metropolitan.	Manhattan.	Edison.
Number	11	8	8 installed 16 ultimate
H.P. each normal rating	4,500	8,000	5,500
H.P. each maximum rating	6,600	12,500	8,000
Aggregate rated H P.	49,500	64,000	88,000
Aggregate maximum H.P.	72,600	100,000	128,000

From the large number of units, we may assume that these are the largest machines the manufacturers cared to produce.

Larger engines have been built for use aboard ocean liners, and as conditions are in many ways much more severe aboard ship than on land, it should be possible to have still larger units if central station engineers really demanded them. The following characteristics are given of the engines of the Kaiser Wilhelm der Grosse:

Two engines, triple expansion, four cylinders; diameters 52, 89.7, 96.4, 96.4 ins.; stroke, 68 8 ins.; piston speed, 885 ft. per minute; revolutions, 77 + ; steam pressure, 178 lb., rated h. p. of each engine, 15,000.

The steam turbine has now been perfected so that many plants are ordering them, and in a year or so a great many will doubtless be in operation.

The turbine presents some characteristics which will, I believe, affect our decision in regard to the arrangement and number of stations for a given system. Although much has been written of them lately, they may be briefly alluded to here.

This type of prime mover has decided advantages over reciprocating engines for driving many classes of electrical machines, as it gives ideal conditions for the parallel operation of alternators and synchronous apparatus on account of its uniformity of angular velocity. We are assured that steam turbines run together in parallel with the same facility as hydraulic turbines have always done. It is well known that many difficulties in the operation of 60 cycle apparatus disappear when the supply of power is from water wheels, and if the steam turbines are to help us in this respect it will be a great point in their favor.

There is every reason to believe that the use of superheated steam with turbines will be a comparatively simple matter, as the turbines will have no internal rubbing surfaces or cylinder oil. Exhaust steam from turbines, being free from oil, may be condensed and returned to the boilers, and this will be an important consideration in many plants now purchasing city water for boiler feed and which find the extraction of oil too difficult and expensive to permit the water being used a second time.

Due to the high speed at which turbines are operated, direct current machines seem to be ruled out on account of commutator troubles.

Perhaps the greatest advantage of the turbine is its economy of floor space. In the paper presented by Mr. Sniffin, before the American Street Railway Association of last year, the statement is made that the Westinghouse-Parsons turbine requires about 80 per cent. of the space needed for the vertical and not over 40 per cent. of that wanted for the horizontal engine. This statement is based on a station layout with a clear space of seven feet in all directions between machines. This type of turbine being horizontal, requires less head room and consequently a cheaper building by a considerable amount than the vertical engine. Mr. Sniffin's curves place the required building capacity for turbines at about 50 per cent. of that for vertical engines.

The Curtiss turbine of the General Electric Company is of the vertical shaft type and while it requires more head room than the Westinghouse-Parsons machine, is very economical of floor space. The following table gives the principal dimensions of some of the sizes which are now being built.

CURTISS TURBINES AND GENERATORS.

Size.	Height.	Diameter.	Floor Space.	R.P.M.
500 k.w.	12′ 2″	7′ 8″	46 2 sq. ft.	1800
1500 k.w.	16′ 10″	10′	78 5 "	900
3000 k.w.	22′	14′	154. "	600
5000 k.w.	27′	14′ 10″	175. "	500

WESTINGHOUSE-PARSONS TURBINES AND GENERATORS.

Size.	Height.	Dimensions.	Floor Space.
400 k.w.	7′ 6″	19′×5′	95 sq. ft.
1000 k.w.	8′	43′×8′	344 "
5500 k.w.	15′	50′×12′	600 "

For comparison, the following is the floor space required by the vertical cross-compound condensing engines of a well known maker. The figures include the space required for an alternating current generator between the frames.

Size.	Dimensions.	Floor Space.	R.P.M.
500 k.w.	15′×22′	330 sq. ft.	120
1000 k.w.	21′×24′	504 "	110
1500 k.w.	22′×28′	616 "	100
2500 k.w.	23′×32′	736 "	90
3000 k.w.	23′×34′	782 "	75

The height would in all sizes exceed that of a similar size of vertical turbine.

The steam consumption guaranteed for the above mentioned Curtiss turbines are attractive, especially at light loads. The figures are given in dry steam per k.w. hour; and for purposes of comparison with results per i.h.p. they have been reduced by assuming an efficiency for generator and turbine of 85.

Size.	Pressure.	Vacuum.	Steam per k.w.h Full Load.	Steam per k.w.h Half Load.	Lb. per I.H.P. Full Load.
500	150	28	20½	23	13
1500	150	28	20½	22	13
3000	150	28	20½	21.5	13
5000	150	28	20½	21	13

The simplicity of the turbine leads us to believe that the high efficiency will not decrease with use nor by reason of lack of adjustment. The method of guaranteeing the efficiency of generators and engines together will permit this guarantee to be checked more closely than has ever been possible with large engines and generators, on which separate guarantees have been given.

I believe that the cost of labor for engine operation will be considerably cheapened with the turbine, and this and the other advantages shown should greatly reduce the necessity for very

large units. If, therefore, steam turbines are to make the operation of smaller stations (with a suitable number of units to handle the load economically) equal in efficiency to some of the largest plants now installed, it will be advantageous in many cases to install several stations in place of one, and obtain all the saving in distribution and safety against shut-downs that go with such an arrangement.

There are, of course, certain cases where a location cannot be secured convenient to coal and water in more than one place, but these cases are rare. Boston, New York, Chicago and nearly all our largest cities afford opportunities for securing a number of sites, all practically of equal desirability so far as facilities for getting supplies are concerned.

ADVANTAGES AND DISADVANTAGES OF LARGE CENTRAL STATIONS.

The advantages may be summed up from what has been previously said, and consist mainly of the following:

The location of the station on the one most suitable site for the coal and water supply.

The reduction of floor space by the use of large units.

The economy of fuel secured by the use of large generators and engines.

The economy of labor and general superintendence secured by the use of large units in one building.

The saving in first cost effected by the installation of a large station with large units.

The economy of operation secured by serving many sections of a city with different hours of maximum demand from one station, due to the better load-factor obtained.

The installation of a large station presupposes supplying a very large territory from one source, and in order that the coal and water supply may be convenient the chosen location is generally much farther from the load than when it is divided among several plants. This involves a greater expense for a distribution system, although this may be minimized by the installation of high-potential current or by local conditions.

The economy of floor space by the use of large units will always be an important consideration where land is valuable, but the economy in this direction with the steam turbine may lead the designer of the future to give less consideration to this point.

The added economy of fuel, labor and general supervision in large units will also be reduced somewhat even with the large

turbine units, and the first cost of the machines themselves will undoubtedly decrease per unit capacity with increase of size. However, the reduction in cost of turbine generator installation from the prices now paid for generators and slow speed reciprocating engines should be considerable and permit smaller units than are now feasible. This will undoubtedly be true after development charges have been cared for.

It is a question whether there is any saving in the first cost in the installation of very large stations, except in prime movers and generators. The construction of double and triple decked boiler rooms, long coal handling apparatus and coal pockets high above the ground, involves heavy expenditures without compensating advantages. It is probable in the case of some large stations in this city that they could have been built to half their capacity as cheaply per unit as to the ultimate size. The size of the units in either case would probably have been the same.

The principal disadvantage of the very large station is the danger to a system if the disabling of the station leaves the company without a source of power, or takes away a larger portion of its supply than can be cared for by overloading the remaining plants. It is with this point in view that I have attempted to bring out all the points which may make smaller stations worthy of more consideration than they frequently get.

The stations in this city are wonderful examples of good design in all features which tend to make them reliable and free from dangers of serious breakdown and interruption of service. As one designer said in describing his station, it was built to withstand anything but an earthquake or a bombardment. While it may be possible to build such a station, I do not believe that there has been a single station built, and I do not look to see one, which is free from weak points capable of causing interruptions. These features are apparently unavoidable; and while accidents due to them may not do any serious or expensive damage, they may render the building untenantable to employees or to enough of them to cause an interruption to the service.

The recent breakdown at the station of the Niagara Falls Power Company is an instance in point, and while such occurrences have been rare, the one in question left Buffalo without Niagara power for eighteen hours, and part of the Niagara Falls district was without power for nearly as long. I do not think an officer of a large company will look on a like condition without considerable apprehension. The trouble at Niagara is reported

to have been started by a lightning storm which resulted in destroying the cables leading across the bridge from the generator room to the transformer house. Now that it is over, engineers say that there should have been two routes for these important cables, and a number of suggestions may be made to avoid a repetition of the difficulty.

Shut-downs have occurred in some other large stations during the experimental periods of their operation, and while these were doubtless due to poor material or workmanship that had not been weeded out, the failure of material or errors of employees may occur after years of use, and the results are likely to be the same.

Instances occur in this city where cables may be damaged by one cause or another, and the results would not be very different from the Niagara breakdown. Rheostats for the fields of generators may be the weak point in another station; switchboards exposed to flying pieces in another. These weak points can generally be corrected, but the fact is that they now exist and are in my opinion possible sources of trouble.

I do not wish to go on record as advocating a greater refinement than is commercially justifiable, and perhaps this point has been reached by the designers of the large stations. The point I do wish to make is that smaller stations need not lack many of the advantages of the large ones, and with a number of them in place of one large plant, the necessity for excessive refinement ceases to exist.

A paper read at the 176th Meeting of the American Institute of Electrical Engineers, New York, April 24, 1903.

SAFETY DEVICES IN CENTRAL STATIONS AND SUB-STATIONS.

BY PHILIP TORCHIO.

A review of general principles followed in the design and arrangement of electrical apparatus of generating stations, transmission lines and sub-stations and a list of safeguards against breakdowns and devices for localizing and clearing faulty elements of the system. Advantages of storage and reserve supply to ensure continuity of service to customers.

The importance attached by central station managers and consumers to the reliability of service has been brought to bear so strongly upon the designing engineers and manufacturers of high-tension apparatus that the problem of safety has received, and is still receiving, even in its details, the study of every engineer identified with high-tension central station work. This applies not only to the designing but also to the installing and operating of central station apparatus.

What has been achieved is therefore the work of many men, of many experiments, often failures and costly trials and worries; and even now it cannot be said that the problem has found its final and general solution. Therefore I shall approach the subject along broad lines, so as to invite discussion and suggestions on the characteristic features aiming to increase the factor of safety or to insure continuity of service.

High-tension transmission systems may be overhead or underground, or composite overhead and underground. For moderately high voltages, up to 15,000 volts, the transmitted current can be generated directly or can be obtained from step-up transformers. For higher voltages, step-up current only has been used up to the present time. All these different conditions create special

requirements for each individual system. In this brief review no attempt has been made to enter into special details particular to any individual case. What follows applies more or less generally to all systems.

Mechanical Reliability.—In this connection no attempt has been made to deal with the feature of mechanical reliability of the generating systems, though it is as important for the mechanical equipment to be safe and reliable as it is for the electrical equipment to be so. In fact the general principle of subdivision and independence of different generating units may be considered to find its application throughout,—from coal supply at the boilers, through the mechanical and electrical equipment at station and transmitting lines, to the receiving substations.

Electrical Reliability.—Proceeding from the generating station to the transmission line and receiving substations, we find the following characteristic features more or less generally adopted or considered desirable from the aspect of reliability of service, Some of the safeguards given in the list appear perhaps as unnecessary and expensive refinements, and probably they would be so for a large number of cases where continuity of service may not be considered absolutely essential. In a large situation, for instance, the lighting and power of a large city, the conditions are different; and if for these conditions safety cannot be obtained in any other manner, these refinements become of paramount importance.

GENERATING STATION.

1. Installation of storage battery on field-exciter bus, at generating station.
2. Equipment of reverse-current relays and circuit-breakers on exciter generators.
3. Equipment of overload relays with time limit and circuit-breakers, on motors of motor-generator exciter sets.
4. Separation and mechanical protection of generator leads of different generators. Also proper insulation and protection against capacity discharges of cable leads.
5. Connection of each generator to bus-bars by means of two oil switches in series preferably arranged to close independently and open at the same instant.
6. Sub-division of bus-bars, in different sections, enabling operation of generators in different groups. Also selector switches on each generator, enabling the same to be operated on at least two sections of bus-bars.

7. Tie-connections between different sections of bus-bars, enabling us to make, if desired, combinations of different sections or even one common bus-bar.
8. Overload and reverse-current relays on generator switches, these being connected to signal lamps until they have proved their reliability for actual tripping of main switches.
9. Selector switches on feeders providing means of connecting each feeder to at least two sections of bus-bars.
10. Duplication of oil switches on each feeder circuit, preferably arranged to close independently and open at same time.
11. Overload relays on each feeder, with a variable time limit, in inverse proportion to the amount of current.
12. Separation of all wiring and busses inside the station by means of ducts, fireproof septums and grooves in walls, and proper protection against capacity discharges, by the use of good glass or porcelain insulators.
13. In connection with very high voltage step-up transformers, provide low-tension synchronizing busses for generators and switches on the l.t. side of step-up transformers, thereby avoiding synchronizing on the h.t. side of transformers, or closing of h.t. switches on dead transformers.
14. Avoid installation of single pole main switches for each phase of the circuit, and also synchronizing with one pole switch closed and synchronizing transformer across the gap of the other pole switch.

TRANSMISSION LINE.

15. Duplication of transmitting lines to important centers of distribution, selecting if possible different subway routes, or independent transmission lines.
16. Mounting of suitable end boxes on ends of cables at all terminals. Also possible equipment of spark arresters on each end of underground cables.
17. Protection of underground cables in ducts by the use of good fire-proof material.
18. Protection of cables in manholes, using preferably separate manholes for high-tension cables, with asbestos or iron covers on each cable, etc.
19. Protection of lead sheath of cables against electrolysis, either by laying cables in vitrified ducts and rubber cushioned racks in manholes, thereby making the cable insulated from ground along its route, or laying heavy bare copper

wires along the route of cables and connecting solidly to their lead covers in each manhole, these wires providing a secure metallic path for the current, which leaves the cable sheaths to return to the grounded bus at the railway station via the wires suitably connected to the railway return feeders.

20. Protection of transmitting and receiving stations operating overhead transmitting lines by improved lightning arresters.

21. Grounding of neutral of three-phase transmission lines for very high voltages. (General practice in the California transmission plants.) In the case of very high voltages, this grounding seems a necessity.

22. Possibly grounding of neutral for lower voltages and underground cables. (This is done in several places, as for instance, in Chicago, on the 2200 volt 3-phase, 4-wire, 60 cycle system, as well as on the 9000 volt, 3-phase, 25 cycle star-connected system). From the point of view of reducing strains on insulation, this grounding of neutral seems unnecessary for moderate voltages, though it could be made use of for locating accidental grounds on the system, and in indicating and eventually disconnecting the affected feeder, which would be troublesome to locate on a system without grounded neutral and operating several feeders from same bus-bars.

23. Avoid operation of high-tension lines at different frequencies when lines are mounted on same pole line. This to avoid doubling of strain on insulators when two wires of different lines become crossed.

SUBSTATIONS.

24. Separate lines entering substations should preferably be operated independently, laying out independent h.t.. busses and transforming apparatus on each line, the transformed current being delivered either to a common set of bus-bars or to independent sets of bus-bars, if the service will allow of this subdivision. In rotary substations, while the rotaries operate in parallel on the d.c. side, they can be fed from independent h.t. lines not operated in synchronism. This allows feeding each substation from different groups of generators at the generating station, or even from different generating stations. In the case of a.c. stations with transformers

feeding into a common secondary set of bus-bars, the primary lines must necessarily be operated in parallel, and therefore from same bus-bars at the generating station. This prevents us from attaining the advantages of duplicate lines and independent sources of supply, as in the case of rotary substations. For this reason, in a.c. systems of secondary distribution, as extensively used in waterpower plants, the adoption of independent groups of generators and independent feeding lines to important centers of distribution is not common. In important cases it may be advantageous to subdivide the customers' supply on different circuits fed from independent lines and transformers operated from different sources of supply. The New York Edison Company operates at present the generators at its Waterside station in two independent groups and whenever a substation has more than one rotary converter in service, the several rotaries are divided among different feeders, fed from different groups of generators at the generating station. The rotary converters being operated in parallel on the d.c. side, the distribution of loads between different feeders and consequently between groups of generators is easily and perfectly accomplished. This distribution is regulated by the system operator at the station, who instructs each substation how to subdivide the loads among the rotaries. The system is laid out to still further subdivide the groups of generators, if the further addition of generators will make it desirable.

25. Receiving lines should be equipped with oil switches and overload relays with variable time limit in inverse proportion to amount of current. When more than one line is feeding a common h.t. bus or independent transforming apparatus operating in parallel on the l.t. side (for instance, rotary converters), each line should also be equipped with reverse-current relays, with variable time limit in inverse proportion to the amount of current, the time limit for these relays being a fraction of the time for the overload relay. Reverse-current relays without time limit are too sensitive to momentary irregularities on h.t. system and cause trouble on this account.

26. Inside the substations all h.t. wiring and construction should be laid out along the same lines mentioned in case of generating station. Also, the low-tension apparatus

and connections should be properly laid out, avoiding crowding and crossing of cables, keeping cables of different polarities separate, and protecting them by means of ducts, septums and pipes as much as possible.

26a. On very high voltage receiving stations, the closing of h.t. switches on transformers subjects them to heavy strains which can, in most cases, be avoided by making alive the transformer from the low-tension side, if the common bus-bars are already fed from another set of transformers. In case of a single set of transformers, it may be advisable to leave the high-tension side of transformer closed all the time, especially in water-power plants.

27. For protection of lines from overloads or short-circuits on transforming apparatus of large capacities, oil-switches with overload relays should be considered preferable to h.t. fuses. The switches should be of proper capacity and should be equipped with locking relays for overloads, exceeding the safe breaking capacity to avoid blowing up the oil-switch. The breaking capacity of an oil-switch will to a great extent depend not only on the character of load, but also on the amount of power back of the short-circuit.

28. Compound-wound rotary converters and eventually also plain shunt-wound rotary converters operated in parallel on a common d.c. bus should be protected by some speed limit device to trip the a.c. and d.c. circuit-breakers on the rotary, when speed exceeds the normal by a certain fixed percentage. The sample here shown is a speed limit device developed by the company with which the writer is connected, in conjunction with a firm which manufactures measuring instruments, adopting their standard mechanism for speed indicators.

29. It is desirable to protect the d.c. side of all rotary converters with circuit-breakers to operate in connection with the speed limit device above mentioned, and also in connection with a reverse-current relay on the d.c. side of the rotary. This reverse-current relay should be equipped with a variable time element in inverse proportion to the amount of reverse current; d.c. overload relays seem to be unnecessary.

30. All relays at different points of the system and their time elements must be properly adjusted, to operate the differ-

ent circuit-breakers in the proper order, so that if a trouble is once cleared by the opening of certain circuit-breakers, the other relays reset themselves in the normal position, leaving the rest of the system in operation.

31. Emergency connections between different generating stations are considered desirable and have found favor in connecting different water-power plants and also in connecting large generating stations in the same city, as in New York.

32. Of first importance in a lighting situation in a large city is the equipment of storage-batteries at every substation. One large New York company, for instance, has installed or under contract twenty-two 8,000 ampere-hour, 135 volt batteries, and more may be installed in the future.

33. In closing this list of safeguards, it may be added that in all high-tension work, great care should be used in applying tests to the apparatus, especially in making insulation tests on generators, cables, line and transforming apparatus. Breakdown tests can be made on samples, but it is unwise to strain unnecessarily the insulation of the complete plant near the breakdown point. Close inspection of the installation will finally give more satisfactory results than loose inspection and severe tests.

NOTE.—During the reading of his paper, Mr. Torchio referred to a type of lightning arrester tested in Europe and designated as a lightning arrester of the series type. The description of this lightning arrester was presented at the meeting of the Italian Electrotechnical Society on January 20, 1902. The theory of the lightning arrester is not clearly explained by the inventor, although seemingly the apparatus gives good results. It is claimed that the presence of this apparatus on lines equipped with standard lightning arresters causes the latter arresters to cease discharge at any slight atmospheric disturbance as noticed previous to the installation of the series type lightning arrester.

This is an important feature, from the fact that the lightning arrester does not wear out on account of slight static discharges which are always present on transmission lines, and which wear out the apparatus if kept in constant use. By freeing the lightning arresters from this constant wear they would be in better condition to do the work when the emergency arises.

A paper read at the 176th Meeting of the American Institute of Electrical Engineers, New York, April 24, 1903.

MULTIPLE VERSUS INDEPENDENT OPERATION OF UNITS AND CENTRAL STATIONS.

BY PETER JUNKERSFELD.

Practical difficulties encountered in the operation of central station systems. A statement of the troubles that beset the electrical engineer on the many different links between coal-pile and translating device. An argument for independent or sectional operation of every central station system.

The tremendous development in the application of electricity has opened immense fields, which to central station men are continually presenting new problems and graver responsibilities. In all centers of human activity the extended use of electricity is closely associated with the success, well-being and comfort of the public, as well as of individuals. The home, club and hotel; the office, factory and mercantile establishment; the church, theatre and public place; the streets at night, and the great transportation systems,—all these are thrown into confusion and disorder on even a slight interruption in the supply of electrical energy.

All members of the INSTITUTE are more or less familiar with central station systems, the principal features of which, in the larger cities at least, have been developed along fairly uniform lines. The many practical difficulties of operation, largely influenced by local conditions, are matters of vital importance from both commercial and engineering standpoints. The object of this paper is to call attention to some of these difficulties, with the hope that this will result in a full and profitable discussion.

The direct current systems of generation and distribution for

lighting and general power, and for street railway work, are inherently somewhat elastic. Satisfactory multiple operation of generating units, thus giving a high average station economy, was early accomplished. In large cities the adjacent systems supplied from different stations were gradually tied together, and resulted usually in a large network of interconnected mains supplied at points of greatest density of load by feeders from the nearest generating stations. The equalizing effect between different points of network greatly increased the stability of such systems, which are often further improved by the use of storage batteries properly distributed.

The quality and continuity of direct current service with this arrangement, has, in most cases, been very satisfactory. However, on account of the heavy fixed charges and losses in operating a large number of small generating stations—many with necessarily poor economy—the limitations in reducing cost of production were very serious indeed.

In the largest cities, having a rapidly increasing load, operating costs have been considerably reduced by alternating current generation, high potential transmission, and rotary converter substations. While these transmission and conversion systems have been developed and fairly well standardized as to general features, there is often still much to be desired in their operation. Systems operating with synchronous generating and converting apparatus and delivering current to the more elastic direct current network, are especially sensitive to any irregularity in the operation of the prime mover itself or in any of the transmission or conversion units. It is not to be understood that the central station service in large cities is less reliable than before, but that a peculiarly unfortunate feature has been introduced. This temporary disadvantage has in most cases been more than offset by decided improvements and safeguards affecting the continuity of central station service.

The primary cause of trouble may usually be traced to the failure or unsatisfactory performance of apparatus; the mistakes or the inattention of men handling apparatus; or mechanical injury and interference from some exterior source. Troubles of one kind or another, even with the best modern systems, are always possible on the many different links between coal-pile and translating device. In a large central station system supplying direct current, these links might be enumerated and troubles classified as follows:—

Mains and services.
Low tension feeders.
Substation apparatus.
High tension transmission lines.
Generator, prime mover and auxiliaries.
Steam supply.

Troubles in wiring or translating devices on consumer's premises are usually more directly under the control of the consumer than of the central station.

These different classes of central station troubles are all more or less liable to occur, but the prevalence of any one class or number of classes of trouble depends upon the character of the different installations, and on local operating conditions. In the discussion of these different classes of trouble the writer would, as a matter of illustration, refer to conditions in Chicago where all 25 cycle high potential transmission and direct current distribution is underground. In the outlying districts the 4 wire, 3 phase, 60 cycle distribution is overhead.

Mains and Services.—Formerly, Edison tube was principally used for all underground mains. The more recent practice has been to use, largely, cables in conduit giving less trouble than the Edison tube, which is true also of services. However, miles and miles of the old tube mains are in service to-day, and must necessarily remain in service for years to come.

Any trouble, either on mains or services, is usually confined to a comparatively small area by the blowing of strips in the feeder junction boxes. The total amount of current that could be " pumped " into such a short circuit is limited by the drop in mains and feeders, at least back to the substation bus-bars. Obviously, the duration of such a short circuit depends on the condition and relative carrying capacity of the " short " and the fuse strips back of it. The drop in mains may be such that it is impossible to deliver enough current to burn off the trouble or blow the fuse strips. These cases, while rare, are very annoying. Sometimes they will " clear " only to start again at an unexpected time, occasionally even making it necessary to remove junction box strips and thus cut out the troublesome section until permanent repairs can be made.

Low-Tension Feeders.—On account of the larger carrying capacity the energy delivered on short circuit is very much greater in feeders than in mains. The total length of conductor in feeders being much less than in mains, the number of troubles

with equally good construction are correspondingly less. Furthermore, instead of tubes, cables have been very generally used for several years. This improved construction also makes the actual number of feeder troubles less. Serious trouble on feeders, when it does occur, however, obviously affects a much larger area than trouble in mains. The extent of area affected depends also on the arrangement of bus-bars and class of apparatus in station or substation.

Substation Apparatus.—In substations supplying direct current, rotary converters with their accompanying step-down transformers and potential regulators are used almost exclusively. The direct current ends of these rotary converters are often worked in multiple with an old generating station, at least during the peak hours of one or two months in the early winter. A storage-battery with end cell switches for discharging on two or sometimes three different potentials is an important adjunct to a substation. The batteries in all substations are often discharged simultaneously at time of peak on principal generating station, or in an emergency; at all other times they are allowed to float on system. They are charged either by using a booster or direct from a rotary converter equipped with sufficient regulator and transformer capacity for working at the higher voltage necessary for charging.

Even in a substation having a storage battery and a subsidiary steam plant, all of the annual k.w.h output, except a few per cent., is supplied to distribution system through the rotary converter. Special precautions are necessary to guard against interruption of service, as the radius of possible transmission of large powers in case of trouble is very much greater than in the case of services, mains or feeders

The characteristics of a rotary converter are such that it will carry an enormous overload with very little drop in voltage. Serious troubles or short-circuits, whether they occur in the rotary converter and accessories, in the d.c. connections or in the a.c. connections, will be violent and are liable to be destructive unless the damaged unit can be quickly and effectually disconnected, both from the a.c. transmission and the d.c. distribution systems. The localizing of trouble and the effectiveness of disconnecting depends on the arrangement of the a.c. bus-bars and the automatic safety devices.

The practice of operating practically all units on a single set of bus-bars, at least during long-hour light-load period in the direct

current generating stations, undoubtedly had some influence on the earlier substation bus-bar arrangements. In many large substations all rotaries are operated from one set of bus-bars; in others they can be operated on either one of two sets of bus-bars. Another arrangement consists in running all rotaries from a single bus-bar arranged with disconnective knife-switches, so that each rotary or group of rotaries could be operated independently from its own transmission lines. An improvement consists in replacing the disconnective knife-switches with remotely controlled oil-switches.

With the latter arrangement, each rotary or group of rotaries can be operated all in multiple if necessary or advisable, and be quickly sectionalized in case of trouble on any one transmission or conversion unit. An example is shown in Fig. 1, which gives the scheme of principal connections in a substation that was put into service about one year ago. There are twelve 500 k.w. rotary converters arranged in three groups of four, each group supplied from its own high-tension line and delivering current to its own section of the direct current bus-bars. The incoming lines, apparatus, cable connections and switchboards, and the low-tension feeders to street, are all located and arranged to prevent a bad burnout spreading from one group to another.

On each rotary converter there is mounted a direct current circuit-breaker operated only by means of a 125 volt trip-coil. A centrifugal speed limit device on shaft closes the trip-coil circuit, thus disconnecting the rotary converter from d.c. bus-bars, and preventing its running away, the causes of which are well known. A reverse-current device also trips this circuit-breaker in any case of trouble that would draw more than a predetermined amount of energy from the d.c. bus-bars.

The oil-switches on each individual rotary converter outfit, and those used for tie-switches, are all equipped with overload attachments, which are so adjusted that they will open only in case of serious trouble. The tie-switches should also be equipped with interlocking devices, so that these tie-switches between lines can be closed only when the two sources of e.m.f. are in synchronism. The low-tension feeders in most of the large Edison systems are provided with very heavy fuses and often with solid links. The adjustment of overload attachments on oil-switches must, therefore, also be made for heavy loads and with due consideration for the particular conditions involved in each individual case.

Transmission Systems.—In most of the larger cities the 25

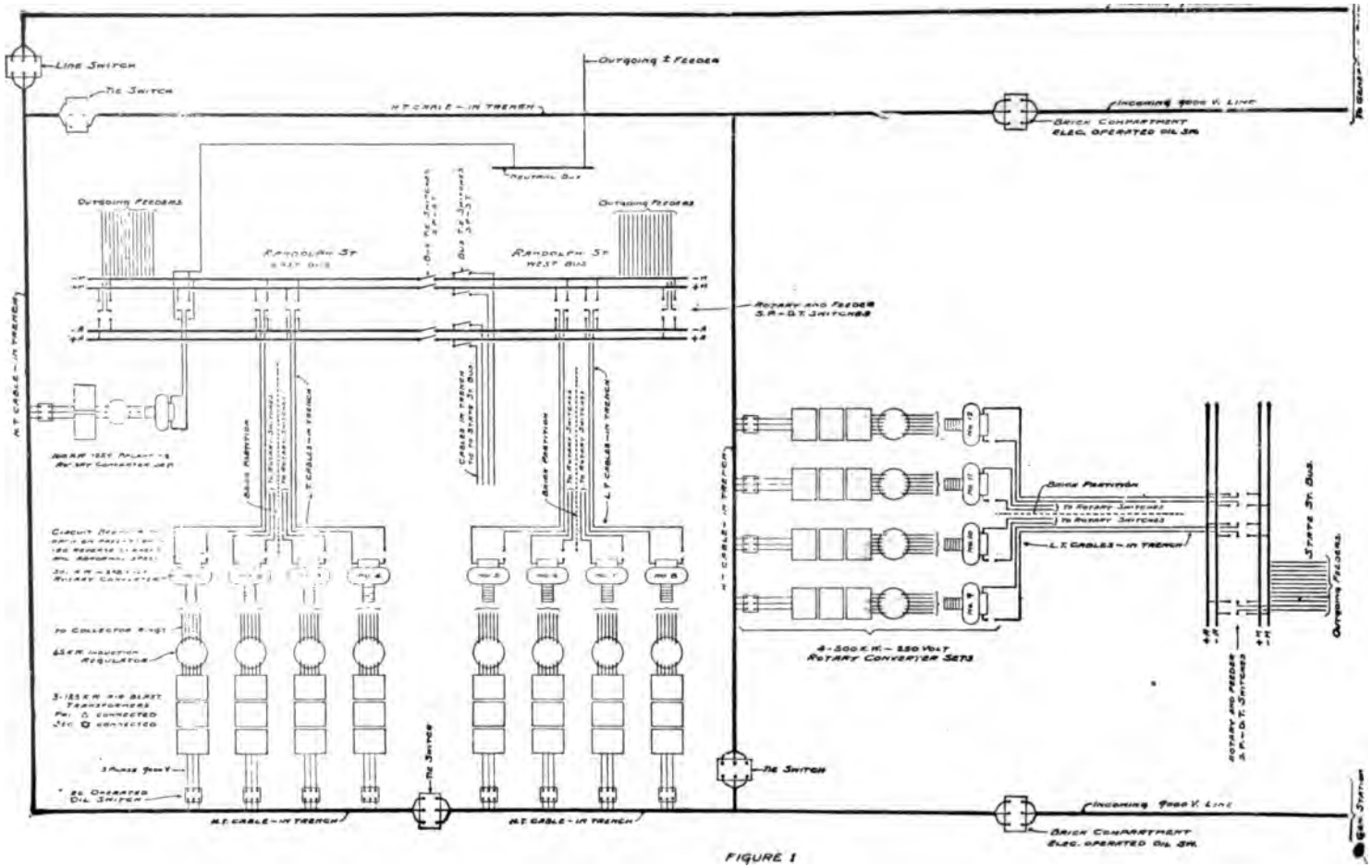


FIGURE 1

DIAGRAM OF PRINCIPAL CONNECTIONS IN A SUB STATION

cycle transmission systems are operated at voltages varying from 6,600 to 13,000 volts. Much higher voltages have been successfully used on through trunk lines in several other cities. This, however, is obviously a very different condition. The large transmission systems with their multiplicity of lines, cable terminals and oil-switch connections have grown into networks that are continually becoming more complex. As each and every case of serious trouble anywhere on a system having almost exclusively synchronous apparatus necessarily affects every part of the system, the possible chances for trouble affecting any one of the thousands of customers, are also continually increasing. Commercially, this is a very serious matter indeed, especially when we consider that with many of the more desirable customers the greatest possible security for continuous service is of first importance.

Realizing this fact, many central station engineers have taken extraordinary pains with high-tension cable work and in some cases have succeeded in making the transmission network in itself one of the most reliable parts of the central station system, except in so far that inherently this high-tension network with its synchronous apparatus is lacking in elasticity.

This has been the experience in Chicago, where a 2,250 volt, 25 cycle transmission line supplying rotary converters, was first put into service about six years ago. Since then the transmission voltage has twice been doubled. The first line, three and one-half miles long, supplied one substation having 200 k.w. capacity in rotary converters. The resulting high-tension system, shown in Fig. 2, will, by next fall, aggregate about 60 miles, supplying nineteen substations with approximately 24,000 k.w. installed in rotary converters and 4,000 k.w. in frequency-changing motor-generator sets.

About twelve months ago the potential was raised to 9,000 volts. The previous and subsequent experience indicated many desirable improvements. Until this time the system was supplied only through delta-connected step-up transformers from double current generators.

The capacity effect of lines was found to be such that in event of slight ground on one phase, it might result in an excessive rise of potential and very severe strain, if not an actual breakdown, on some part of the system. The grounding of the neutral on this high-tension system has been attended thus far with very satisfactory results. As star-wound 9,000 volt alternators were

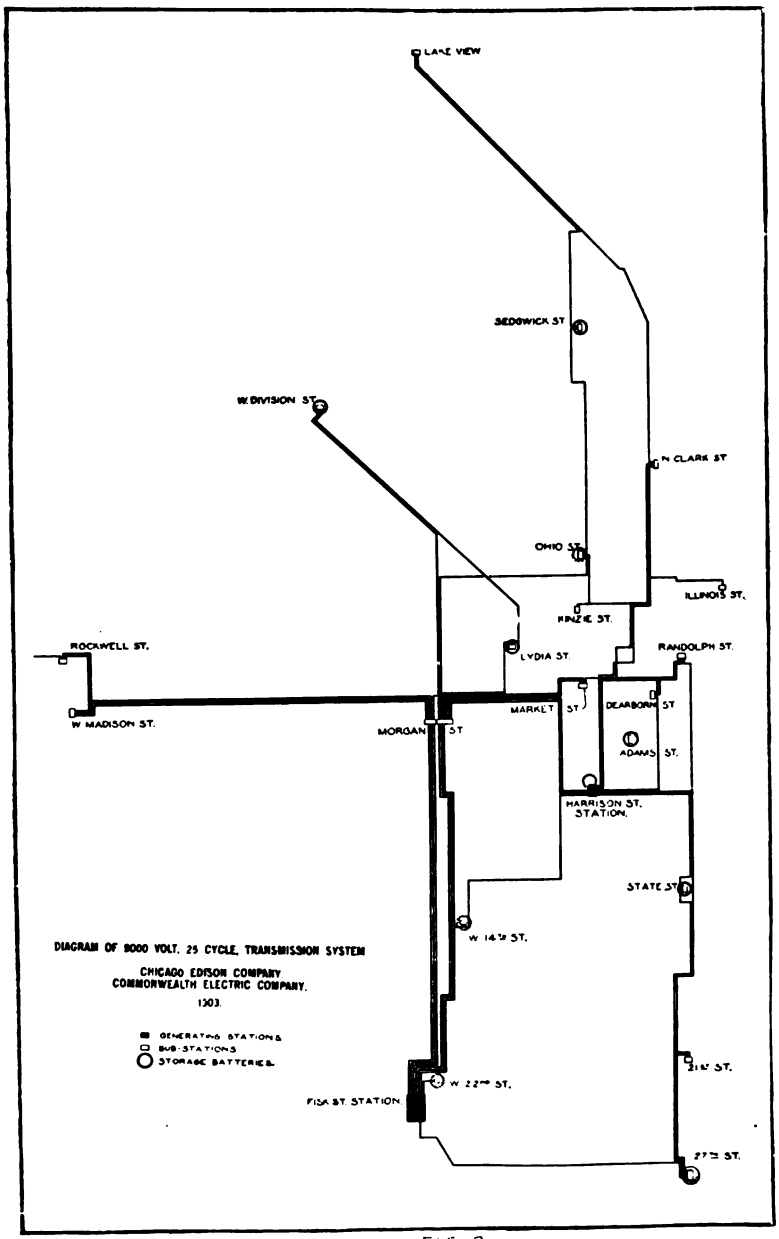

LAKE VIEW
SEDGWICK ST.
W. DIVISION ST.
N. CLARK ST.
OHIO ST.
ILLINOIS ST.
KINZIE ST.
ROCKWELL ST.
LYDIA ST.
RANDOLPH ST.
W. MADISON ST.
MORGAN ST.
MARKET ST.
DEARBORN ST.
ADAMS ST.
HARRISON ST. STATION.
STATE ST.
W. 14TH ST.
W. 22ND ST.
FISK ST. STATION
DIAGRAM OF 8000 VOLT, 25 CYCLE, TRANSMISSION SYSTEM
CHICAGO EDISON COMPANY
COMMONWEALTH ELECTRIC COMPANY.
1903.
GENERATING STATIONS
SUB-STATIONS
STORAGE BATTERIES.

FIG. 2.

installed, the common point of winding was in each case connected to ground. Practically all high-tension transmission cable installed during the past two years consists of No. 4/00 three-conductor paper and lead-covered cable. The thickness of paper wall on each conductor is 6/32 inch, over all is 4/32 inch, and lead wall is $\frac{1}{8}$ inch.

The arrangement and installation of terminal appliances is obviously of great importance. All forms of fuses and air-break switches have been abandoned, so that at present the main circuits are made and broken only under oil. Various forms and methods of making up joints and cable-heads were tried. These are now made up in parts, so that the lead sleeve or cylindrical part of head is put in place after the individual joints have been made and insulated with paper tape. The sleeve or cable-head is then filled with a special compound, which is a non-absorbent of moisture and has a much higher dielectric strength than the paraffin which was formerly used. The process of filling is such that every minute particle of moisture is expelled.

The selection of routes for transmission cable is made with a view to provide two or more lines on different streets if possible, at least in different groups of conduit for each substation. The cables are isolated and mechanically protected, so that the spreading of a bad " burnout " in either high or low-tension cables will be prevented as much as possible. A well-designed and constructed conduit and manhole system is therefore essential. Overhead connections to an extensive high-tension underground network are a source of trouble to be avoided, if possible. When unavoidable, these overhead taps should be isolated by means of transformers.

Generator, Prime Mover and Auxiliaries.—The necessity for operating all units in multiple for long hour periods in order to obtain good station economy, still exists to a very large degree. During the past ten years the sizes of units in the largest stations have been increased from 800 and 1,500 k.w. to 3.500 and 5,000 k.w. The number of units, however, in any one station has often been decreased, making multiple operation of at least a large portion of plant more necessary than before, and also placing much greater dependence on any one unit. Such stations have been and are still passing through a critical transition period. Every case of serious trouble on generator, engine or auxiliaries affects the entire system; but it frequently happens that the system cannot be sectionalized even into two parts without

serious sacrifice in engine economy. The gradual increase in number of units will only partially relieve this situation.

The engine-driven unit is ordinarily one of the most uncertain elements in the central station system. Duplicate units are often installed and operated side by side under apparently the same conditions, and one, for a time at least, will prove much more reliable than the other. There is so much fitting, so many fine adjustments and valve settings, all of which must be done with great care, precision and patience. Much depends also on the faithfulness and the skill of the men in immediate charge of the apparatus. This is true of any similar apparatus, but particularly of the large engine-driven units operating in multiple on transmission systems.

With an arrangement of bus-bars, high-tension lines and substation apparatus similar to that shown in Fig. 3, generating units can be operated independently, and a certain amount of shifting of load can be done at the larger substations having four or more units in service. Rotaries can be shut down one at a time, transferred to another generating unit or another station and again put on load. During peak-hours there would be shifting which would introduce some additional chances of trouble due to possible mistakes of men handling apparatus, which, in that case, would partly offset some of the advantages of sectionalizing.

In this respect, a very decided advance would be the use of a prime mover giving practically a straight line economy, such as the steam turbine. The differences between one-half load and full load performance for short hour periods will not be great enough to warrant much shifting. The auxiliary apparatus, particularly the condensing plant, is frequently a cause of trouble. The " sticking " of pumps, " dropping " of vacuum, and similar reports, are heard occasionally in every steam plant. The arrangement should be such that the condensing plant and auxiliary apparatus and the excitation of any one unit are simple and positive in operation and normally independent of every other unit.

Steam Supply.—Practically every steam plant has its own peculiarities in piping and arrangement of boilers, but in most cases all boilers are in one room. The bursting of a steam-pipe or boiler-tube fills the entire room with steam instantly, making it impossible to close a valve in the ordinary way. The location of boilers in two or three different rooms or floors and the providing

of means for closing valves from inside of engine room has lessened the danger of a shut-down. The placing in separate rooms, as far as circumstances will permit of the boilers and piping corresponding to each generating unit and connecting only

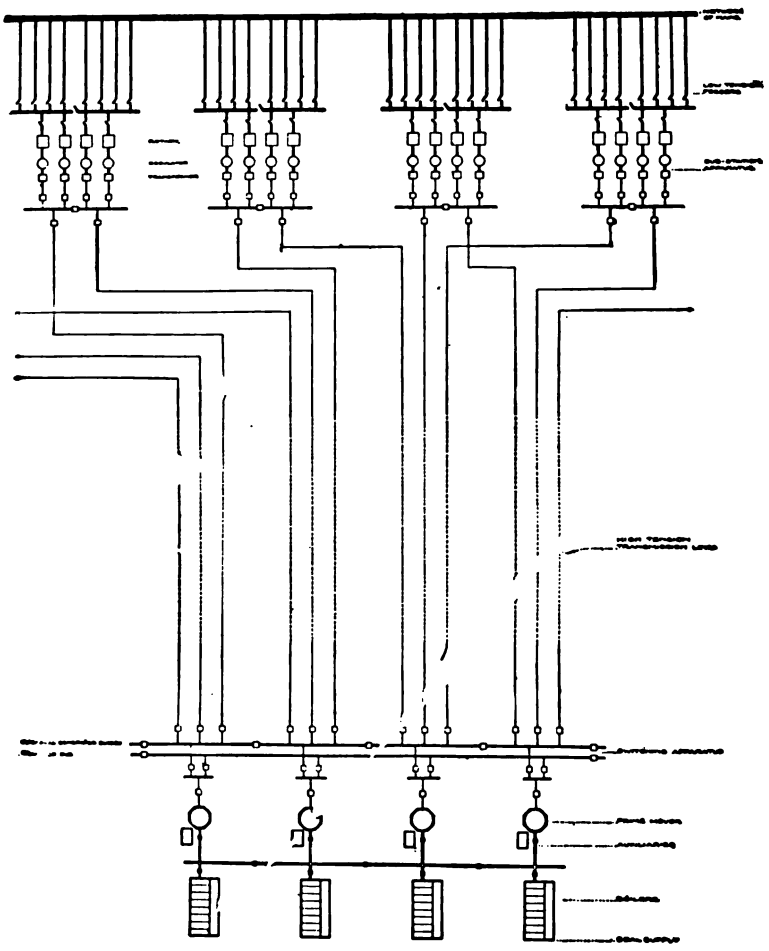


FIGURE 8.

through fairly quick-acting remotely controlled valves will further lessen this danger.

With careful operation, customers' troubles (bad or interrupted service) that are chargeable to the boiler room are few while those of the central station manager are many. Investiga-

tions, experiments and some improvements have been made from year to year, but the buying and economical handling of coal and making of steam still involve problems that are worthy of the very best attention, both as to the cost of operation and reliability of service rendered. These problems are especially important when we consider large stations which consume 2,500 or 3,000 tons daily, and the many possible chances of delay and interruption between the coal mine and the boiler room.

General Considerations.

A survey of the various classes of trouble between coal pile and customers' service indicates at once the unfortunate feature of large modern transmission systems. True, as has been done in some cases, induction motor-generators might be used instead of rotary converters. The substation apparatus would then be much less sensitive to sudden fluctuations in engine speed, or to line disturbances due to short-circuit on some other part of the system.

The first cost of motor-generators of 500 k.w. and 1,000 k.w. capacity installed complete is, however, from 15 to 25 per cent. greater than for rotary converters with accessories. Under ordinary operating conditions there is a difference of from 3 to 5 per cent. in efficiency in favor of rotary converters. The power-factor of the rotary converter is obviously much better than that of the induction motor. The characteristics of a rotary converter are often a practical advantage in cases of trouble on low-tension feeders or mains.

In some cases, for instance where it is necessary to run a large number of converting units from a long transmission line which itself is subject to heavy fluctuations in potential and frequent interruptions, it may be advisable to use motor-generator sets. In the large majority of cases, however, in both lighting and railway work, the rotary converter has been found the best and most economical. If the objectionable features thus introduced into large systems cannot be overcome, the result can at least be minimized by judicious sectionalizing.

The electrostatic capacity of these large high-tension cable systems is such that there is necessarily a practical limit to the mileage of cable that can safely be operated as an interconnected network. In the 60 miles of 9,000 volt, three-phase, 25 cycle lines previously mentioned, the charging current as calculated will be about 16 amperes. At the present rate of increase in mileage the condenser effects will soon be troublesome and possibly pro-

hibitive, as troubles may occur which will result in building up a potential at some point and breaking down insulation on apparatus that was comparatively safe on the smaller system. In that event, and with several very large units all in multiple, the amount of power delivered on short circuit would probably be so great that it could not safely be interrupted by any oil-switch thus far built.

In a rapidly growing system provision for a reasonable amount of sectionalizing can easily be made. The investment in the portion of central station system between coal pile and customers' service most directly involved, is, under most conditions, divided approximately as follows:

Station real estate, building and generating apparatus	35% to 45%
Transmission system cables and conduit	3% to 6%
Substation real estate, building and converting apparatus	10% to 15%
Feeders and mains cables, conduit and Edison tube	40% to 48%

These percentages are greatly influenced by local conditions, such as average and maximum density of load; value per duct foot of underground conduit; average length and voltage of transmission; cost of real estate and character of buildings. In railway plants, the investment in substations and that corresponding to feeders and mains will be less, while the investment in transmission lines will be somewhat greater. A considerable capacity in storage batteries will, under load conditions obtaining in most large systems, decrease slightly the investment in the first three, but would not affect that in feeders and mains.

The provision for sectionalizing will not increase the investment or operating costs, either in substations or in feeders and mains In the transmission system it may, under some conditions, slightly increase the total mileage of lines; but such an increase in the 3 to 6 per cent. thus involved is a very small increase in the total investment in entire system.

A review of power houses indicates that there is a wide difference in cost of station buildings. This difference is a matter partly of engineering and partly of management. Taking the total cubical contents of six of the large modern station buildings, we find that from 6 to 10 per cent. is devoted to coal storage and that the complete buildings vary from 100 to 240 cubic feet, and from .95 to 2.5 square feet per k.w. rated generating capacity.

The boiler room portion of the same stations vary in total net cubical contents from 65 to 130 cubic feet per rated boiler horse-power, while the engine room portions vary from 40 to 90 cubic feet per rated engine horse-power. As practically the same types of boilers are used, the former depends almost entirely upon the design and arrangement; but the latter depends largely upon the type of generating unit adopted. In the case of vertical turbine-driven units, the figure for this portion of plant can be reduced by at least one-half.

The tendency, however, in power house design is toward a much more liberal allowance for space for all equipment. The high-voltage generators of large capacity and multiplicity of lines demand extraordinary switching apparatus which requires considerable space. A suitable arrangement and reasonable isolation of switching apparatus and connections need not require any additional space and should preferably be much simpler than that in many existing stations.

It would seem, therefore, that in the large modern power house, sectionalizing and even entirely independent operation of units can be provided for with very little, if any, additional investment in the generating station or in any other part of the system.

While the independent operation of generating units would tend to minimize the effect on cutsomers of many central station troubles and thus increase the coefficient of reliability, there will also be some disadvantages. A heavy overload or perhaps short-circuit coming entirely on one unit or group of lines might trip the oil circuit-breaking switches on lines, and the sudden release from load severely strain the prime mover. This cause would be improbable if, as indicated in Fig. 3, each generating unit supplies at least two different substations and when only part of the load would be thus released on any one generating unit.

If a short-circuit occurs on a feeder supplied by a small group of rotaries the percentage of overload is larger, and after one rotary trips the others will quickly follow. This might not have occurred with a larger group, when the percentage of overload would have been correspondingly less. All transmission lines should be equipped so that oil circuit-breakers at both ends of line open automatically in case of trouble, whether the entire system is operated in multiple or independently.

In the latter event, if time limit attachments are used with overload devices at the station, the amount of energy delivered at the point of breakdown might not only slow down the engine

but draw enough energy from network to trip the circuit-breakers on all rotaries supplied from the particular generating unit. If operated as shown in Fig. 3, this would mean, under full conditions, an overload of 50 per cent. on the remaining rotaries in each substation supplied from three different generating units; 100 per cent. overload on those supplied from two, and a total shut-down of such small substations as are supplied exclusively from the particular unit in trouble. Usual result: low pressure on part of direct current system; no trouble elsewhere.

In event of multiple operation of the entire system, with several units in service, a large amount of energy from the station bus-bars would be delivered until time limit overload devices at the station and reverse-current devices at the substation cut out the troublesome line. Usual result: heavy fluctuations in pressure on entire system, until line is opened at both ends, several machines shut down and sometimes a total shut-down of transmission system.

During the hours of light load the transmission system would naturally be divided into fewer parts or perhaps all in multiple. In event of a shut-down during these hours, the capacity of storage batteries would be so much greater in proportion to load that the drop in pressure would not be so serious.

The successful operation of large systems necessitates the maintaining of a well-organized operating force of competent and experienced men. Every operation involving the starting or shutting down of a generator, line or substation unit should be carefully regulated and checked to reduce to a minimum the possibility of a mistake. In one of the large stations now under construction provision is made for a LOAD DESPATCHER, whose office will be convenient to the operating switchboard and who can control absolutely the transferring of load between all generating, transmitting and converting units, with the same implicit confidence and accuracy of judgment and action as can the train despatcher on an important railroad system. His office should be a clearing house for all orders concerning operation of system.

After considering some of the advantages and disadvantages of multiple and independent operation in large underground transmission systems, it might be of interest to consider small overhead systems. The latter are operated independently, in very many cases with satisfactory results as to reliability of service rendered. In order to secure more economical engine per-

formance, it was necessary to adopt large units operating in multiple. This step also improved the reliability of service rendered, particularly where each feeder emanating from the bus-bars continued to supply its own independent system. If these small systems of taps radiating from a center of distribution at feeder ends had been arranged into one interconnected overhead network covering a large area, the coefficient of reliability with the same character of construction would undoubtedly have been decreased. These systems, usually supplying current for induction motors and for lighting, are fairly elastic; but on account of the higher potential, usually 2000 volts or more, a short-circuit obviously affects a very large area and often the entire system. The matter of regulation being comparatively easy, there is, therefore, a distinct advantage in operating independently the different feeders instead of on an interconnected network. With an overhead system exposed to the elements and so many chances of interference from an exterior source, a modern station is usually the more reliable part of such a system, and therefore there is little necessity of sectionalizing the station. As a precautionary measure, however, and to facilitate future extensions and repairs, stations should be designed so that this can be done.

In conclusion, it might be said that considering responsibility for the business and return on investment, every central station system should be designed, if not for independent, at least for sectional operation. In the very large stations, the independent units from coal pile to distributing network, or to rails, should be effectively isolated to make a total shut-down practically impossible. The matter of independent, sectional or multiple operation at different hours of the day or days of the year is entirely one of local conditions, which may change frequently. Great care and constant attention is needed to maintain a fairly uniform and consistent coefficient of reliability on every part of the central station system. Independent and even sectional operation will mean a small sacrifice in operating costs. With a system properly designed, this matter, then, becomes to the central station management a plain business consideration; to take the risk of inferior service and possible shut-down, or to pay a premium in the form of very slight sacrifice in operating costs and thus obtain an additional safeguard for superior service to all or such groups of customers as business requirements may demand.

DISCUSSION.

PRESIDENT SCOTT:—We take up to-night a number of papers dealing specifically with different combinations in the system of distribution, and the first paper will be that on "Economical and Safe Limits in the Size of Central Stations," by Mr. H. A. Lardner, of New York City.

Mr. Lardner read the paper. (See page 407.)

PRESIDENT SCOTT:—The next paper is on "Safety Devices in Central Stations and Substations," by Mr. Philip Torchio, engineer of the New York Edison Company.

Mr. Torchio read the paper. (See page 417.)

PRESIDENT SCOTT:—We are fortunate this evening to have among those who are to present papers, two gentlemen connected with large and important companies. We have just heard from the engineer of one of the larger companies in New York, the large lighting company, and the company which provides power for general distribution. We also have with us a gentleman from Chicago, one of the other large cities of the country, who represents one of the most notable plants of the country. Mr. Peter Junkersfeld, engineer of the Chicago Edison Company, will now present his paper on "Multiple versus Independent Operation of Units and Central Stations."

Mr. Junkersfeld read the paper. (See page 425.)

PRESIDENT SCOTT:—The papers which we have had this evening are of exceptional value on account of their particular character. In dealing with the subject of central station practice, they have not gone into generalities, they have not dealt with matters in a theoretical way, but we have had in the last two papers, in particular, what we might call heart-to-heart talks from the men who have been operating large stations for a considerable time. The burden of the papers, particularly of the last two is notable—it is not the general theory of the interrelation of parts, not on the characteristics of engines or dynamos, of efficiency or regulation, nor do the papers refer to those elements which come up in connection with the design of the station beforehand, but they have more to do with the operation of the station, with the things which affect the man who runs the station They have to do more particularly with the emergency conditions, with safety devices; and through all the papers we have this sentiment—how shall we protect the station against emergencies and interruption of service? We might be led to think that these papers are chapters from experience, and one might almost conclude that Mr. Torchio has given us the results of thirty-three accidents and shut-downs in his system, but we fortunately have already been assured that this is not entirely the case, by Mr. Lieb's statement incorporated in my introductory remarks—that this same system has been running since its beginning, always with some current on its lines, and for some ten years with no interruption of the service.

We are in debt this evening especially to one of the mem-

bers of the Committee on Papers, who has had this meeting in special charge. He is the superintendent of motive power of what was the Manhattan Railway Company, and is now a part of the Interborough Rapid Transit Company, of this city. He has given me a list of some gentlemen whom he suggests I call on for discussion this evening, and I will reverse the order in which he has placed the names, and begin with the signature at the bottom and call upon Mr. Henry G. Stott.

MR. STOTT:—It seems to me that to-night is a good time for us to look back. We have been told a good deal about modern tendencies. History seems to repeat itself. We started out fifteen years ago with one machine and one circuit all the way through; a little later it became a question of adopting two or three circuits, and having them so divided as to suit the size of the units. A little later the size of the units was increased, and also the size of the feeders which they supplied. Then it became a problem of combinations, how to adapt the feeders to the size of the machines. At that time everything was run, practically, with high-speed engines and high-speed belted generators. Following that came the period of slow-speed engines, and we began to look then into the possibilities of multiple operation. Multiple operation meant, instead of running five, six or eight small units on perhaps 50 per cent. load for the greater part of the time, for the service to be combined on one or more machines, thus producing a fair load factor. Then as soon as multiple operation came, with low speed engines, we began to look around for some further development; and there seems to be at the present time a tendency to go back to the higher speed generator, such as with the steam turbine.

The steam turbine is practically an unknown quantity to most of us, and while some results have been published, yet it has not been in use long enough to justify a prediction that it will displace reciprocating engines. Reciprocating engines to-day are built with higher steam economy than is claimed for the turbine. I understand that tests with the Sulzer engine in the Moabite station show a consumption of 8.97 lbs., of steam per indicated horse-power. The larger units in operation in New York to-day are all approximately consuming about 13 lbs. of steam per indicated horse-power. That corresponds approximately to 19 lbs. per kilowatt hour. The best of actual records of the steam turbine is just about that. By going into triple expansion engines, a step which seems obvious for railway power or lighting plants, we can get down 20 per cent. lower than that, without any trouble at all. I had a message from the Boston Edison Company to-day, in which they advised me that with a 1200 h.p. compound condensing engine, with 98° of superheat at the throttle, they got a steam consumption of 11.57 lbs. per indicated horse power. At the present time I feel personally, in regard to the steam turbine, that we will have to return the Scotch verdict of " Not Proven," and wait until we get actual results.

The feature of the floor plan, the space in relation to the general size of the plant and the unit, has been referred to. I think a little consideration will show that the size of the generator unit has nothing to do with it. It is the size of the boiler room. If we can reduce the size of the boilers, we can reduce the size of the station, but to get an economical distribution of steam from any plant, we must run the boiler room parallel to the engine room. I believe you will find that the limiting feature in all large stations, no matter what the size of the generator unit, you must have a certain size of boiler unit; and to get the best distribution of steam, even though the units only occupied one-fourth of the space claimed for the steam turbine, you would have to space the steam turbine units at approximately the same centering distance as you do the steam engine, so that the economy of floor space I do not think is a very important point.

Coming to the transmission lines, the claim has been made, and I think it dwells in the minds of many able engineers, that the high-tension lines are very dangerous. I differ from that. I think the high-tension underground cable is the safest thing we have—a great deal safer than low-tension. If you have a short-circuit in a low-tension cable, it may burn up a thousand feet of the cable before you can stop it. If there is a short-circuit on a high-tension cable, with proper safety appliances on each end of it, it does not destroy more than two feet of it. We have quite a large capacity on the bus-bars in the Manhattan plant—over 45,000 k.w., all in multiple—and we have had short-circuits on the high-tension feeders of 11,000 volts, and the result is a puncture such as you would get from a testing transformer, not destroying more than two feet of the cable, whereas with a short-circuit on a 600-volt direct-current cable, a large amount of cable may be readily destroyed.

I think the storage battery has found its proper place as an assurance against shut-down and not as a means of economical operation. That statement is probably open to discussion. It seems to be almost impossible to find a condition in which the storage battery pays for itself as an investment. I believe it is used essentially as an insurance, and not as an element in economical operation.

The idea which pervades all of these papers, namely; the returning to the single operation of units on a certain number of feeders, or employing a certain number of substations, without multiple operation, seems to be a backward step. It is a confession of weakness in our safety devices. Is it not a better solution to improve the safety devices and operate in multiple and thereby gain the maixmum economy of station operation? The price of coal is soaring all the time and apparently always will do so, and in the operation of a plant coal forms over 60 per cent. of the actual cost of power; and it is therefore most important for us to do everything possible to economize. This can only be done by running the units as near full load as possible, and to

do this we must run in multiple. The separation of high-tension apparatus can be very easily carried out, and it seems to me that by means of proper appliances as indicated in Mr. Torchio's paper, and as actually carried out, there is no difficulty whatever in making a station practically safe in all kinds of operation. I have seen an actual short-circuit in a station with four 5,000 kilowatt machines in multiple, and an oil switch, take care of it perfectly, long before the attendant could touch the switch and throw it out. With a switching apparatus brought down to such perfection as this, it seems to me that we ought to be very careful about reducing the efficiency of operation of our plants by going into independent units or plants. I believe this covers all the points I had in mind to present this evening.

THE PRESIDENT:—We have with us this evening a gentleman who has been connected with central station work for some ten or fifteen years, Mr. Herbert A. Wagner

MR. WAGNER:—I can add very little to the remarks which have been made to-night in the papers that have been read. I have recently been connected with the engineering work of the Boston Edison Company, and there we have so far operated all the alternating current generators and feeders in multiple. We have had practically no trouble. The generating station, until three years ago, was used for alternating current distribution only. It is now used entirely for transmitting current to substations from which current is distributed on the three-wire direct current system. All these substations are equipped with motor-generators in place of rotary transformers, and I attribute the freedom from many of the troubles which other central stations had to the use of motor-generators in place of rotaries. A large proportion of the motor-generators are induction motor-generators and therefore the troubles which are often caused by a great amount of synchronous apparatus are obviated. Of course, there is something to be said against the use of motor-generators. The first cost is something more; the power-factor with induction motor-generators is lower, but with a proper apportioning between induction motor-generators and synchronous motor-generators that can be improved.

The company is now building a 50,000 k.w. station, in which turbines in 5,000 k.w. units are to be used entirely in place of engines. This station will probably be operated in sections, but that has not yet been definitely determined. I would like to correct the statement which Mr. Stott made; since he evidently is misinformed. The engine economy which he quoted in reference to the Boston Company, refers to the cross compound engine and not triple expansion. I think the German practice and experience has shown that there is nothing to be gained by the use of triple expansion over compound engines, especially without superheating. They have carried superheating to a very much higher degree there than we have here, as they have used independent superheaters. In this country nothing over 100°, I think, has

been reached, and that is much above the average practice, which is 75° to 80°. With a high degree of superheating, I think the cross compound can be made fully as economical as the triple expansion engine. Single cylinder engines, with high degree of superheat, have almost equalled compound triple expansion engines, but the difficulty of using such high degrees of superheat is almost insurmountable, especially with the type of engines used in this country.

PRESIDENT SCOTT:—Is Mr. F. A. Waldron, here? If so, we would like him to participate in the discussion

MR. F. A. WALDRON:—As I have prepared a paper, covering detail tests, to be presented at the June meeting of the American Society of Mechanical Engineers, I hardly think it would be just to the Society to which I belong, or to myself, to anticipate this paper in any of the remarks which I might make this evening. Therefore, I will make a few general remarks, in which all quantities will be stated in round figures, subject to such modifications as more detail may develop.

After listening to the opinions and remarks on the steam turbine, this evening, by different members, I find that my own feelings in relation to the turbine, two years ago, were the same as theirs are to-night, although, when I drew the following parallelism, I did not realize that so unanimous sentiment existed.

As a disciple of E. D. Leavitt, of reciprocating engine fame, my experience with the turbine has been very much like the experience of the Provençal, in Balaze's " Passion in a Jungle," when he discovered the blood-stained panther in the cave.

1st.—A fear and a desire to get as far away from it as possible.

2d.—A natural curiosity to see how the " animal " would act (with a very grave doubt in my mind that it would act as I wanted it to.)

3d.—Its graceful outline; the space occupied; the alluring " blue book " by Mr. Hodgkinson, on how little water it consumed—gradually overcame my natural temerity and I became more curious.

4th.—I approached the " animal " with the determination of finding out how it would act, when awake, feeling all the time that it would be well to keep a knife (hammers and monkey-wrenches) at its throat.

5th.—To make a long story short, I have become acquainted with and learned to admire the " animal," and although I have never laid down to sleep with it, I wanted to very badly, last August, when a wire in the field broke, and I did not sleep for 48 hours, while it was being repaired.

Personally, I regard the turbine in relatively the same light as the sewing-machine, and I do not think, for one minute, that the reciprocating engine builder need take the same stand that the spinster did, at the time the sewing-machine was invented, and petition Congress that it be suppressed. It has its special field and is not, in any way, a universal power panacea or a patent medicine remedy for power ailments.

On the other hand, it is a remarkable stride toward the goal of economizing power distribution, and the claims made for it by the builders have been substantiated in every way. I have found the following points in the machine that appeal most strongly to the business man and to the engineer in charge of the operation of plants at the present day:

(*a*) Simplicity.
(*b*) Ease of operation.
(*c*) Economy.
(*d*) Lack of multiplicity of moving parts.
(*e*) Continuous or commercial efficiency.
(*f*) Floor space.
(*g*) Cost.
(*h*) Cost of buildings.

I have not named these in their order of importance, as one is almost as important as the other, and will take up, briefly, a discussion of the points in the order above named.

(*a*) SIMPLICITY.

After the machine is properly placed, balanced and started, there seems to be (outside of defective materials), nothing in it which can give any trouble.

(*b*) EASE OF OPERATION.

Two lubricators which require filling twice each day; an occasional trying of the oil, cooling-water cocks and the small air cocks on top of the bearings, together with an occasional lubrication of the collector rings, is all that the running engineer has to look out for, in as far as the turbine and its generator goes.

(*c*) ECONOMY.

The Yale & Towne outfit consists of a Westinghouse-Parsons turbine and a 400 k.w., 2-phase, 240-volt, 7200 alt. generator, driving induction motors from ½ to 40 h.p.

This is the first plant to be operated for regular factory driving, outside of that the Westinghouse Company, having been in service since February 1, 1902.

To be sure, this is a small plant, as compared with those mentioned this evening, but it is the small plant that worries, as to whether it is better to put money into betterments or the coal-pile, since in such the line of such demarkation is very fine.

A breakdown, due to defective forgings, occurred last January, on a new field which had never had a load upon it. This has in no way destroyed our confidence in the machine, and a second unit has been ordered.

With a 400 k.w. load, running at about 150 lbs. pressure, per gauge, at the throttle, with from 10° to 15° superheat and about 27½ inches of vacuum, an economy of approximately 22½ lbs. of water per k.w. per hour at the switchboard, has been obtained. This economy is the result of tests from daily running loads and is in no way a special test; the discharge from the surface condenser determined the amount of water used, and the condenser was tested for leakage before the tests were made.

(*d*) LACK OF MULTIPLICITY OF MOVING PARTS.

This is very noticeable and impressive to one who sees the turbine for the first time, and I shall never forget my disappointment in finding it so simple a machine. The governor and an oil-pump are about all that *seem to be going*, when the machine is running.

(*e*) CONTINUOUS OR COMMERCIAL EFFICIENCY.

By this I mean that it is inherent in the design of the machine to run continuously and at varying loads within certain limits, at its maximum economy, owing to the fact that there are no cross-head slides to get out of alignment; no piston packing to wear and replace; no stuffiing boxes to repack; no valves to reseat or grind up, and no bearings to key up—all of which tend to reduce the daily running efficiency of any reciprocating engine plant.

The effect of changing engineers in a moderate-sized plant, and its effect on the coal-pile, are unknown quantities in so far as reciprocating engines go. We all know however that when the new engineer comes on everything has to be readjusted; and where there is one that knows how to make proper adjustments, there are a dozen who don't, and as a general proposition it is safe to say that the average sized plant, in the course of ten years, gets more engineers that don't know how to make proper adjustments than those who do. This is one of the chances of war which the reciprocating engine owner has to take and as a natural consequence must pay for.

The personal equation of the engineer, and its effect on the coal-pile, is entirely eliminated in the steam turbine.

(*f*) FLOOR SPACE OCCUPIED.

It is possible to place about three times the power, in turbo-generator outfits, in the same space occupied by a direct connected horizontal or vertical engine of approximately the same economy.

(*g*) COST.

The cost of the turbine, with its accessories, ready to run, is from 10 to 15 per cent. less than the reciprocating engine of the same power, provided high-grade makes *only* are considered. You can buy a reciprocating engine equipment cheaper than you can a turbine; but personally I do not think that such are to be classed in truly competitive prices.

Weight, complete, 33,000 lbs.

Weight, reciprocating engine same power, with generator, 200,000 lbs.

(*h*) COST OF BUILDINGS.

The cost of buildings in our particular case per k.w., would be about 65 per cent. of the cost of buildings housing the same amount of power with the reciprocating engine.

There are one or two points in the turbine, especially in the installation of the machine, which should be carefully watched.

1st.—To place the turbine, with relation to condenser, so that there shall be plenty of chance for expansion and contraction of the machine itself.

2d.—In piping up for cooling water, it is well to have two sources of supply; also, an eel-trap and by-pass on the inlet to the oil-cooling coils and the try-cock to an open drip on the outlet of the coils.

The exciter outfit should never be driven by a motor or the turbine itself; an independent, direct-connected set is the only way to do the trick, unless you wish to take chances of shut-down, especially if you have inductive loads.

Oil should be changed and filtered every week.

The present construction of the turbine is such that it has one very weak point which the reciprocating engine has not, and I will mention it, briefly, before closing. The reciprocating engine, designed for a certain horse-power, may have its most economical point of cut-off from a .28 to .33 stroke in the high pressure cylinder. In the event of the vacuum being destroyed and the relief-valve to the atmosphere opening, the reciprocating engine naturally takes more steam and keeps the machinery up to speed, even though it has to carry about .7 or .8 stroke in the high pressure cylinder.

The turbine however will not do this when running from three-quarters to full load. It is necessary for the engineer to be on hand to open the by-pass and cut out the high pressure blades, in order to keep the machine up to speed. This can be done, if the engineer is always in the same place, but he isn't always there. The result is sometimes a shut-down through conditions which are entirely beyond the engineer's control.

I am informed that designs for avoiding this trouble are being perfected.

The electrical end of the machine is of course the one which you are probably most interested in and *that* end is really one which I am at a loss to describe, as the extent of my knowledge in the electrical line is always to keep one hand in my pocket when around any machine generating electricity. Since coming in actual contact with the installation and operation of a turbo-generator unit, the meaning of *power-factor* has been drummed into my head by hard knocks. Should any member of the committee who established the power-factor specifications ever want the position of running the Yale & Towne turbo-generator, under the conditions which we have been running in the past year, I think that after he had been on the job for about six days he would willingly admit that there are two sides to the power-factor question.

I understand that a specification was established by a committee (appointed by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,) which states that the power-factor for alternating current machinery specifications should be based between 90 and 100 per cent., at the normal output of the machine.

If I am not mistaken, at that time these specifications were based on the requirements of the times, and from the best practice and data then obtainable. The induction motor was then comparatively an untried machine. Almost everything in the electrical way was direct current, and the alternating current was taking its place in long-distance transmission and lighting requirements. At the present time, however, and the immediate future, the probable method of power transmission from central stations will be by the alternating current generator and the brushless (induction) motor. This being the case for the average sized plant, a power-factor of from 80 to 85 per cent. will be nearer the average for work of this kind than 90 to 100 per cent. The query then is—Does a man actually get what he thinks he is getting, when he buys his machine? To the electrical engineer, familiar with alternating current, all of this is very plain, but I have met many electrical engineers who have always made a study of direct-current work, who have been somewhat "phased" in the matter of power-factor. Let us assume, for argument, my own case. I place myself at the mercy of reputable builders, stating that I require a 400 k.w. machine. I receive a specification with the standard power-factor of between 90 and 100 per cent. incorporated therein. I purchase the machine and start it up, with the idea of carrying the full k.w. rating of the machine. Upon applying the load, I find that the ammeters show between 25 and 33⅓ per cent. in excess of the carrying capacity of the generator terminals, with proper temperature limits. I also find that the current required to run my exciter is in excess of the requirements in the specification. I further find that the rise of temperature in my field, to carry the load, is more than it should be. Under these conditions, I begin to make inquiries and find that it is very seldom that a plant carrying a purely inductive load reaches a power factor of above 85 per cent. In most cases plants of moderate size, with variable loads, will seldom exceed 82 per cent.

A natural answer to this is, " Well, he ought to have known better." I will admit it; but yet there are hundreds of others I have found since that haven't any idea or conception of this bugbear, power-factor. I hope you will pardon my aggressiveness in this matter, and not take it as an affront to the hospitality which you have extended me in suggesting that a standard specification and rating shall be made for alternating current generators, running under inductive loads, with power-factors lower than those already specified; and in this way large manufacturers would have a specification which, if read by some mechanical engineer, would not mislead him into thinking that he was buying a " gold brick." Some standard form of this kind would undoubtedly be for the mutual advantage, both of the mechanical and the electrical engineer, especially with the tendency to the centralization of large power plants; and, as the induction motor with the turbo-generator is designed to become a potent

factor in the future development of this centralization, it would seem but fair and just that the issue should be looked squarely in the face and met, not only from the standpoint of the expert electrical engineer, but also of the purchaser.

It was only this afternoon that a mechanical engineer, in charge of some large mills in the east, called on me in regard to the question of centralizing a plant aggregating from three to four thousand horse-power, and using the alternating current with induction motors. He was looking at it through the same glasses that I did, when the machine was purchased, namely; that a 400 k.w. machine was good for 400 k.w., regardless of the character of load.

In conclusion, as a general proposition, the electrical engineer has very thoroughly and gracefully placed the turbo-generator proposition up to the metallurgist and mechanical engineer, and it is now fairly and fully up to them to solve the problems of a high speed, and the ability of materials to withstand such speeds under continuous running conditions.

PRESIDENT SCOTT:—On the list of names handed to me appears the name of Mr. E. H. Sniffin. We will be glad to have Mr. Sniffin take part in the discussion.

MR. SNIFFIN:—There is one point which occurred to me, particularly in connection with the steam turbine, and that is the question of economy. I think we are all tolerably familiar with what the reciprocating engine will do, and it is probably a fair statement to say that the steam turbine will not give materially better results, under full load test than the best known results of reciprocating engines. Under light loads, of course the turbine is more economical, but I wish some one were wise enough to tell us what reciprocating engines do in everyday service. I think as we accumulate experience we will find a distinct difference between the inherent, commercial, everyday efficiency of the turbine and the reciprocating engine. This has been already shown by the amount of experience we have had. For instance, at Mr. Waldron's plant he is getting results which will soon appear in his intended paper, and I think will bear out the remarkable commercial efficiency of his plant operated by the turbine. I might say, too, at Hartford, Conn., where there is a good-sized turbine running, 1500 k.w. machine, they have found by pretty careful experiments that they develop, as I recall it, about 1900 k.w. with the steam turbine, as against 900 k.w. for two Corliss engines, with the same fuel consumption. Possibly the engines were not in the very best condition; it may be the valves were not well set, or the internal condition of the engines not exactly as it should be. The turbine, of course, is direct connected, and the engines drive the generators by belting, and to the belt-drive we may ascribe some of the deficiencies of the steam engines, but certainly not all. We should not be misled in comparing the efficiency of two different types of apparatus simply by tests of them. The results obtained by

everyday use give the correct measure. As these new plants are installed and we get the actual results of the commercial operation, I think you will find in the commercial efficiency of the turbine a very marked improvement in general steam plant practice.

PRESIDENT SCOTT:—We would be pleased to have Mr. John W. Lieb, Jr. participate in this discussion.

MR. LIEB:—I will not take up much of your time, considering the lateness of the hour, but will make one or two observations on the papers which have been read. Reading over Mr. Junkersfeld's and Mr. Torchio's paper, one would be almost inclined to think that Mr. Lardner had a great advantage from the standpoint of safety of operation in a considerable number of smaller stations. I think, however, that Mr. Lardner in his statement of the case for a multiplicity of smaller stations, has probably not taken into consideration the extremely important factor in locating such smaller stations in such a city as New York. I certainly do not agree with his statement that it is not a difficult matter to locate smaller stations within the district of New York City; I mean in the Borough of Manhattan. I think any one who has undertaken to operate an electric light station on Manhattan Island will have become very soon convinced of the great difficulties which attend a selection, such as the bringing of coal to the station and the drawing away of ashes, and the liability of annoyance to the people living in the neighborhood. These things are all included in the difficulties of securing a proper location. As the state of the art progressed to a point where it was possible to concentrate the chief generating plant, so that these objectionable features would be minimized, it would soon become evident that such a step was necessary.

I would say also that if prospective customers of the electric light and power companies could read over this very formidable list of all kinds of automatic overload and underload relays, and other things tributary to the operation of a large power station, I am afraid the contracts which come in would be few and far between; as a matter of fact these requisites are rather in the direction of extreme refinement, necessary to secure the greatest regularity of service and the greatest freedom from disturbance.

I notice in these papers a question that is linked very closely with the problem of whether we shall have one large station or a number of small stations, and that is what one of the gentlemen has referred to as the commercial risk. It is perhaps true that if an accident should happen to a large station it may possibly involve a larger territory and therefore a large station perhaps might not be as absolutely safe as a number of small ones; yet that safety can, by proper engineering methods and careful installation, be increased to a point where the risk is entirely a commercial one. I think that has been fairly demonstrated in the operation of the large central stations which have supplied

the larger cities where the exigencies of the services are great; and I would emphasize the absolute necessity, of an auxiliary of storage batteries in such systems of distribution. I think it is perfectly safe to say that the experience of all large central stations operating transmission systems to substations has shown that the storage battery seems an absolute necessity.

It seems to me Mr. Lardner has made a rather formidable list of advantages of large stations and has cited as the principal and only disadvantage the possibility of current interruption; but I am afraid that he has not, perhaps, sufficiently emphasized the very large difference between operating a dozen or more small plants and one large plant; and I wish particularly to emphasize in the case of a large number of smaller plants the volume of what may be called unproductive labor, the people you must keep at the smaller plant, no matter what its output may be. While the various matters which have been spoken of this evening might seem to indicate that the service from these larger plants may perhaps be less reliable than the service from a multiplicity of smaller plants, I think the experience that has been had in that direction already sufficiently demonstrates that the service which the large plants can produce is sufficiently constant and reliable for the most exigent and difficult conditions.

PRESIDENT SCOTT:—Mr. Lieb in his advice to central station designers uses the same sentiments that Mr. Carnegie employs in giving advice to young men—put all your eggs in one basket, and then watch that basket. The subject is open for general discussion and we would be glad to hear from any of the members who wish to speak upon it.

MR. TOWNSEND WOLCOTT, New York:—If I understand the theory of the steam turbine, there would not be the same advantage in the use of superheated steam in it as in the reciprocating engine. The superheating of steam in the ordinary engine is merely for the purpose of preventing condensation in the cylinder, for when saturated steam expands adiabatically while doing work, there is bound to be some condensation, owing to the conversion of heat into mechanical work, but, on the other hand, if the steam expand adiabatically without doing work, there is some superheating due to the expansion. If the work done upon the piston in expansion be accurately adjusted to the equivalent of this superheating, there would be neither superheating nor condensation; the steam would remain saturated. Now, in the De La Val turbine, and I think to some extent in the Parsons, the steam is expanded without doing work upon the buckets, the energy being finally imparted to the buckets by the impact of the swiftly moving mass of steam (or water). This steam, in the De La Val turbine, travels at the rate of about one thousand eight hundred feet per second, and to obtain the highest efficiency the periphery of the turbine should travel at one-half this speed, or about the velocity of a musket ball. This is out of the question mechanically, so at the highest practicable velocity there is a

considerable portion of the kinetic energy of the steam lost in the exhaust or tailings. It would seem to me that the only effect of superheating the steam for such a turbine would be to add to the energy thus rejected; particularly when there may already be some superheating due to the expansion.

MR. W. S. RUGG:—Mr. Lardner has brought up the point that we can expect nearly the same economy in a small station as in a large station. This, I think, is an important point and one with which we are all somewhat familiar, although Mr. Lieb has also shown that the cost of operating a number of plants is increased considerably over the cost of operating a single large plant.

Mr. Torchio has called our attention to the importance of isolating and duplicating the various parts of the distribution system. This is one of the directions in which most advancement has been made in central station practice during the last few years and one which is not as generally known and considered as it should be.

Mr. Junkersfeld called attention to the importance of isolating a boiler plant and dividing it into several units. This is a question I believe which has not been considered as fully as it should be.

All of these points are of great importance and it therefore surprises me somewhat that we have not heard suggested to-night a type of station in which all of the above advantages could be combined. We have yet to hear the first attempt so far as I know actually to lay out a multiple unit station, *i.e.*, a station made up of a number of unit stations each separated from the other by dividing walls but so arranged as to be operated together. In such a station I believe we could combine nearly all of the advantages which have been brought out in the papers, and it could be so designed that the operating expenses would probably be very little more, if any, than the operating expenses of a station occupying one room.

MR. ABBOTT:—The papers this evening are exceedingly important, particularly from an engineers' standpoint, but there may be another side to the question; namely, the standpoint of the general manager. Is it not possible to consider the question of the necessary safety appliances and the question of subdivision of the central station into a number of units as an economic problem, and to consider whether the greater cost of additional appliances for safety or of sub-dividing the given station capacity into a number of smaller units is warranted when compared with the risk of injury to service by omission of safety appliances or concentration of a larger plant in a single building. One of the papers this evening referred to the Niagara plant and mentioned that after the recent disastrous fire some of the engineers were reported to have stated that there should have been two bridges and two sets of cables. It is easy to shut the door after the horse has escaped, and to point out the desirability of duplication of plant after the accident has oc-

curred; but it is very certain that the Niagara engineers in the original design considered a single bridge and one set of cables amply sufficient to meet all contingencies.

Suppose the city of New York should be served for light and power from a single station, and all the machinery necessary for supplying the island be concentrated in a single station and a company should be formed to insure all customers against interruption of service in the same fashion that a fire insurance company assumes risk of loss from fire. Suppose upon the other hand that the necessary plant for serving Manhattan Island should be sub-divided into ten or more different stations. What would be the relative premiums for the two cases? The latter plant would be more expensive to construct and more expensive to operate, but if properly designed there would be almost no possibility of interruption to service, for if one station were incapacitated, the other nine would probably carry the extra duty without difficulty. With one station, even with the best design and most careful operation, occasional interruption to service, for greater or less periods of time, would be likely to occur. The question is whether the extra investment in sub-dividing the plant and the extra cost of operation would represent a capitalization sufficient to pay an insurance company to underwrite all consumers in such a manner as to recompense them for any interruption. This is a business proposition.

Now, would it not be possible for some of us to contribute to the general knowledge on this subject in an endeavor to show perhaps graphically the relation between the number of interruptions to service in the territory served by one large plant as contrasted with the number of interruptions where service is given from several small plants.

MR. JUNKERSFELD:—The question seems to be one of multiplicity of small stations as against one large one. Mr. Lieb pointed out clearly that a multiplicity of plants is impracticable, because the companies must locate their power stations where coal and water can be easily obtained. This has been found true in Chicago also.

I fully agree with Mr. Stott and would rather have trouble on a high-tension cable than on a low-tension one, and in our experience in Chicago we have had very little trouble from breakdowns in high-tension cables. In fact, during the last year, we have hardly known what it was as far as the high-tension cable itself was concerned, except that when interconnected, disturbances were transmitted from one part of the system to another.

The question of the storage battery was brought up by Mr Stott with the statement that as an investment he could not consider it economically. This is largely a question of conditions. In his situation it is possible he cannot see any great saving in installing storage batteries, but in the lighting business, with narrow peak, it is easy to see how a storage battery can be installed and used with profit up to a certain capacity. If you

cut off enough of the peak so that is it more than say an hour and a quarter wide, the battery will not pay. With a peak of one hour the battery will pay better than the equivalent capacity in generating apparatus.

Returning to multiple and independent operation, it has been shown this evening that a multiplicity of plants have some safeguard over one large plant. During the past two years the work in Chicago has been carried on with the idea of sectionalizing the substations and the transmission system. As the generating units were quite large, very little sectional operation was possible on account of the great sacrifice in steam economy with reciprocating engines. With the installation of the turbine units, having a good one-half load economy, sectionalized operation will be entirely possible. I was glad to know that here in New York, they had actually started operating their large plant in two sections, even with reciprocating engines, and I think the fact that they have found this advisable will be given a good deal of consideration in other stations, because what is done in the large lighting stations, is usually based on thorough investigation and wide experience, and is a matter of interest to all stations.

MR. LARDNER:—No one knows better than Mr. Lieb the difficulties of operating many small stations in New York, or of securing locations which will insure the company freedom from complaints due to the annoyance incident to such plants.

I think I have been slightly misunderstood. I do not advocate a multiplicity of plants, but I do advocate sub-dividing into a few plants, perhaps two or three, instead of building only one large plant.

As to the difficulty of securing sites in New York City, there is the site at Kingsbridge, 219th Street; the 96th Street location; the 74th Street; the 38th Street, and the 59th Street and North River. Five suitable locations have therefore been found by the large companies and I imagine the respective engineers each think they have the best site.

MR. TORCHIO:—The only stations the last speaker has mentioned are high-tension stations located on the water front. I wish to ask him if he meant that the New York Edison Company should have adopted several low-tension stations on the water front.

MR. LARDNER:—I suggested the advisability of two or three high-tension stations, not low-tension.

MR. TORCHIO:—Low-tension stations would have been out of the question.

I want to take issue with Mr. Stott in his statement that the storage battery has no standing from the standpoint of saving station capacity. Under special conditions as in New York City, for the downtown district below Eighth Street, supplying the business section of the city, the load of the station is very light during the night hours until 8 A. M., at which time the load increases very rapidly and reaches a maximum about 9 o'clock,

and this load is practically maintained uniform throughout the day until about 5 P. M., when there is a very sharp peak caused by an overlapping of the motor and lighting load. This peak is of very short duration and shows a very sharp drop inside of the succeeding hour. A storage battery can be utilized advantageously at this time as capacity, in connection with the local low-tension steam-generating machines. Since after the load has gone through the sharp drop the battery is no more required as a reserve, thereby deriving the advantage of the battery as capacity without sacrificing the advantages of the battery as reserve during the day.

MR. STOTT:—At what rate do you discharge the battery?

MR. TORCHIO:—We discharge the battery at that period of the day at the maximum rate, the one hour rate. Where we have a lighting-load peak extending for three or four hours, as in the other districts, the result would be different. I have in mind the diagram of the power station of the Milan Edison Company in Italy, operating a transmission line from a water power plant and delivering a good deal of power for industrial motors and for running the street railway as well as lighting in the city.

The load diagram of the power plant, as I remember, is something like this, with a load factor of about 80 per cent. At this time (indicating), when they have the evening peak they discharge a very large battery, which takes care of the lighting load. They sell power in Milan in the neighborhood of $60 per h.p. and that battery, operated only for the few heavy load days of the year, enables the company to sell annually something like 2,000 to 3,000 h.p. additional.

MR. STERN:—Has Mr. Torchio any data as to the efficiency of that battery?

MR. TORCHIO:—The efficiency of the battery is of no importance as a commercial consideration. In the Milan plant supplying energy by water power, the losses in the battery are negligible, as to cost. What one has to consider are the financial results derived from the sale of 3,000 h.p. at $60 per annum, or $180,000 additional revenue.

The meeting then adjourned.

BRANCH DISCUSSIONS.

Discussion at Chicago, May 5, 1903.

Papers presented:

"Economical and Safe Limits in the Size of Central Stations," by H. A. Lardner. Abstracted by Prof. P. B. Woodworth, of Lewis Institute.

"Safety Devices in Central Stations and Substations," by Philip Torchio. Read by W. G. Carlton of the Chicago Edison Co.

"Multiple versus Independent Operation of Units and Central Stations," by Peter Junkersfeld. Presented by the author.

Mr. B. J. Arnold:—I am very much interested in the question of the production and distribution of power, but I cannot comment on these papers for the reason that I have not had an opportunity to read them. I think, however, that in general for lighting work or for power distribution in large cities, I would incline toward the single central-station where it could be economically located, as it usually can be, with the power distributed to substations containing rotary converters and batteries.

European practice seems to favor motor-generators rather than rotary converters such as we use in this country. In Frankfort, Germany, I saw 1,000 kilowatt motor-generators, of which the motors were single-phase, and the generators direct-current, running street railways very successfully, in conjunction with storage batteries, and this was soon after I had been told there were no large sinlge-phase motors running anywhere. The Europeans claim that they get better efficiency out of their combination of motors and generators than we do out of our combination of step-down transformers, and rotary converters, for the motor-generators utilize the incoming alternating current at the line pressure, without the losses of transformation.

When we use alternating current, however, as in railroad work, where we have to go across country long distances, I am in favor of divided power stations It has only been within the last two or three years that I have preferred them, but my judgment now is that we shall run our railroads with power houses of moderate size, generating high potential, and located approximately 20, 30 or 40 miles apart. This eliminates a large part of the equipment we are now using, and brings down the first cost. It is in line, I think, with the recommendation of one of the papers of this evening.

Mr. W. L. Abbott:—Anyone who had the responsibility of supplying 1,000 tons of coal a day for power houses last winter would naturally have made up his mind long ago as to what was the most important feature of central-station operation. It is to get the coal there. To this part of the work my attention of late has been principally directed.

At our Harrison Street power house, which is now about ten

years old, the facilities for receiving coal were thought to be ample, since the Chicago River was on one side and the Alton switch tracks on the other. When the power house was first started fuel-oil was used, but that was soon abandoned and coal was brought into the boiler room by wheel-barrows; the wheel-barrow was superseded by a horse and dump cart, and later by a tramway with push car. Now we have automatic coal-handling apparatus and automatic stokers.

The cost of handling the fuel for all the labor connected with the boiler room has been brought down from about 40c per ton, under the first method—that is, with a wheel-barrow and hand firing—until now it is somewhere between 15c. and 20c. a ton. The difference looks like a very satisfactory saving, but it is probably larger than it should be, and on the consumption of 600 tons of coal a day, a saving of 10c. per ton would be very satisfactory.

In the larger power houses the matter of supply fuel is a serious problem. Some of the power houses now built and projected will require 3,000 tons of coal per day, which means perhaps two train loads. To get this amount of coal into the power house regularly is difficult. Storage facilities will have to be provided in the city for loaded cars, and means must be provided for shifting these cars about.

When dependence is placed on the railroads for rolling stock and for storage, there is continual complaint of unsatisfactory service. Therefore, a large power house should not only have storage tracks of its own, but undoubtedly rolling stock of its own. It should also have a large supply of stored coal nearby during the winter months.

There should also be coal and ash-conveying apparatus and automatic stokers whereby the coal can be moved from the mine to the ash-dump without being touched by workmen. This not only for the saving of expense, but for the reducing of the number of unskilled employees about a power house, which, in these troublesome times with labor agitators, is an important matter only fully appreciated by those who have had to do with it.

Where there are several power houses in one system, the economical way is to run only the larger one as much as possible. Storage battery auxiliaries are also desirable.

It is absolutely necessary to meet promptly an increased demand for power caused suddenly by the formation of dark clouds, the breakdown of an adjacent power house or other similar circumstance. This is not difficult with hand-fired furnaces, but it is impossible with an automatic stoker. The latter takes its own time to get into condition for service. Most of the recent power houses are now supplied with blowers, which put an air pressure under the grates, whereby the amount of coal burned can be doubled or quadrupled.

The most wasteful pieces of apparatus about a power house are the boiler and furnace. The waste in them, counting the two

units together, may sometimes be as much as 50 per cent. of the fuel, and at least one-half of this waste is preventable. The operating engineer and designer should give their particular attention to the boiler and furnace, if great savings are to be secured. In a plant which is consuming two, three or four thousand dollars worth of fuel a day, a saving of even 5 per cent. would be a matter of very great interest to those who pay the bills.

MR. JUNKERSFELD:—I was interested in Mr. Arnold's remarks in connection with using a number of plants distributed twenty thirty or forty miles apart on a road through the country. It seems to me the number and distribution of such plants is dependent upon their size. For instance, if the load is heavy enough to require a fair-sized plant every thirty or forty miles, then perhaps it would be desirable to have them located about that distance apart. If, however, the plants are small, considerations of unproductive investment and unproductive labor would make it desirable to have them fewer and farther apart; that is, if still within the limits of economical high-voltage transmission, and if the reliability of service rendered is sufficient.

I fully agree with Mr. Abbott that the boiler room does not ordinarily receive the attention it should have, either in design or in operation. It must be remembered that the fuel and boiler room expense is a very considerable part of the total generating cost.

The use of forced draught to increase the generating capacity of the station in case of a sudden demand would often be very desirable. It would be the equivalent of storage battery capacity right in the boiler room, made available by starting the blowers. While this might involve either improved furnace construction or increased repairs to furnace and boiler setting, it would seem that a great deal of reserve capacity could be thus provided at a cost per unit of capacity less than that of storage batteries on a narrow peak. I do not mean that we are thus able to discount the value of storage batteries, which are distributed over the system and are, therefore, nearest the points where they can do the most good, but I do believe that under some conditions the use of auxiliary forced draught as reserve boiler capacity for sudden demands of short duration will be found advisable.

MR. H. B. GEAR:—I am chiefly concerned with the problems in connection with the 60-cycle, 2000 volt distributing system rather than the station and substation features of this discussion.

The principle of sectional operation has been generally applied to the 60-cycle distributing system in Chicago. The feeder system is operated separately; that is, a feeder supplies a section of the primary main system which is not interconnected with the mains of any other feeder, and that section of the city is, therefore, not affected by trouble in any other part of the city. In the same manner the secondary distributing system has been kept almost entirely separate. Each transformer, except in a few

cases where the load is very heavy, supplies a separate secondary usually about 800 feet in length. Interconnected secondaries are not desirable until the load reaches a density of about 40 k.w. per 1000 feet of line, or more.

MR. W. G. CARLTON:—I think practically all of the questions in connection with the high-tension, 25-cycle distribution system are treated by Mr. Torchio and I think he was wise in discussing only the electrical troubles and not referring to the mechanical ones. Considering cases of trouble occurring: Out of all the cases of trouble that we have had, here in Chicago on a 25-cycle 9000-volt system, fully three-quarters (probably more) occurred in the generating station and were mechanical; of the other one-quarter that were electrical, nearly all occurred in the generating station. The Chicago Edison Company has been operating at 9000 volts for about a year, and I do not recall now a single case of trouble that was due to a fault in the lines themselves, although one or two cases were due to the damaging of the lines by men working on them.

Mr. Torchio brought out the point of the separating of the lines for different substations. In accordance with this principle our down-town substations each have at least two lines—some more than two—and the machines in these substations are divided in two groups. In case of trouble at the generating station so that an engine has to be taken off and the 25-cycle load has to be reduced in a hurry, the operator knows exactly what lines to open, and in this way no one substation is shut down entirely. In a number of cases we have substations with batteries, and also with rotary transformers. In cases when it is necessary to reduce the load, the supply is cut off the substations where there are batteries.

There is another way that grounding the lead sheath of cables can be done in order to protect them from injury by stray current. This is by breaking the sheath at intervals, possibly every half mile, and grounding the sections at the middle point.

MR. ARNOLD:—I would like to ask Mr. Carlton if he has had any trouble with the breaking down of the insulation right where the cables leave the lead sheath?

MR. CARLTON:—We have had two or three cases not particularly serious—which were due to the ends of the cables not being suitably protected. We have since then taken more pains with the ends of the cables and have had no further trouble. Very careful work insulating the ends of the cable is required.

MR. CRAVATH:—In looking over the plans of several large steam-turbine stations which are under consideration at the present time, I have been impressed with the enormous amount of boiler room required in proportion to the turbine room. As one engineer put it, "I do not know but that we are coming to the time when we shall design our stations in the form of a number of radial units, each unit with a turbine in the middle and boilers on all sides of it." This humorous remark rather serves to call

attention to the fact that it is a nice problem in the designing of a steam-turbine generating station to preserve the symmetry of the station so it can be enlarged section by section, and at the same time get a large enough battery of boilers within reasonable piping distance of the turbine unit which they are to supply, without introducing objectionable features in the boiler arrangement.

MR. ARNOLD:—When I made my previous remarks I had in mind heavy trains, and when you consider a train that takes 1500 h.p. continuously you can have your stations thirty miles apart and have plenty of use for them if you have a number of these trains to pull. I should have expressed myself more clearly. On an ordinary interurban road with trolley cars, of course you would not need a power house every 20 miles, but when you consider the heavy trains, you will, in my judgment, need the segregated stations, and the complete elimination in the substations of step-up and step-down transformers.

COMMUNICATION AFTER ADJOURNMENT BY CARL SCHWARTZ.

The tendency in recent years is towards the erecting of single large power stations, not only supplying the growing demand for current, but absorbing smaller stations. It is evident that the arrangement of such stations must be made as perfect and safe as possible.

In the large modern central stations, even partial shut-downs occur very seldom, but influences of any kind affecting only a single part of such a station may lead to its complete shut-down, while were the same aggregate power delivered from several separate stations, if one should be disabled the others would be able to maintain the service at least on part of the system.

The growing demand on the central stations has required the use of larger and larger generator units, but a practical limit in the extension of central stations and the size of units is soon reached. For this reason it will be absolutely necessary to operate large systems in independent sections.

The most serious objection which could be made against independent operation of the generating units and the transmission systems is that the load cannot always be equally divided between the different units, and requires, therefore, a larger number in operation, some with uneconomical loads.

A suitable switching arrangement and a proper distribution of the feeder lines will, however, insure a reasonably economical load on all units, especially at time of heavy load.

The difficulty of uneconomical load with ordinary steam engines loses its importance with steam turbines whose efficiency we are told varies only about 3 per cent. from half load to 50 per cent. overload.

Independent arrangement and operation of generating units and transmission lines with a flexible switching arrangement, thus giving all the advantages of a large power station in erection,

operation and management, without running the risk of connecting these extremely large amounts of energy together continuously, is of great importance in the further development of large electrical distributing systems. The extension of large central stations and the extension of high-tension distributing systems both at present limited in regard to safe operation, are practically unlimited with an independent arrangement.

The question of one or several power stations, located far apart from each other, but all supplying a common system, is often influenced by circumstances of peculiar kind and depends therefore in every case, on particular local considerations.

Discussion at Pittsburg, May 11, 1903.

The meeting was called to order by the Chairman, Mr. Lincoln, who introduced President Scott.

Mr. Scott made a few remarks concerning the proposed Union Engineering Building, and called upon Mr. C. W. Rice, Chairman of the Building Committee, for a statement regarding the present standing of the matter.

Mr. Rice gave a very interesting account of the efforts of the Committee to interest Mr. Carnegie, these efforts finally resulting in his offer of one million dollars for a Union Engineering Building Mr. Rice said that great credit was due to both Mr. Scott and Mr. T. C. Martin for their persistent efforts to interest Mr. Carnegie.

Mr. Scott then opened the subject of the evening by a discussion on "Tendencies of Modern Central Station Development."

The papers presented at the New York meeting of May 24th were read in abstract.

Mr. Hodgkinson:—In the paper by Mr. Lardner reference was made to steam turbines applied to large central stations. There is no doubt that steam turbines are every day establishing themselves as reliable units.

The difficulty of multiple operation of alternators as pointed out by Mr. Lardner is entirely at an end. I know of 400 k.w. Westinghouse turbines at the Westinghouse Air Brake Company's works having a 2½ per cent. variation of speed between no load and full load, and whose parallel operation through all variations of load has never left anything to be desired.

Some comparisons have been made of floor space occupied by turbines and it has been shown that the Curtis turbine, by reason of its main shaft being vertical, occupies less floor space than the Westinghouse turbine. If, however, we consider the cubical contents of the machine, this difference in some cases disappears and in others is much less in evidence.

Another point, however, should not be lost sight of, that by reason of the shaft being vertical and having considerable top weight it would be supposed that much more massive and better foundations are necessary than would be the case with the shaft horizontal.

A turbine and generator with horizontal shaft needs substantially no foundation at all, only something that will hold the dead weight of the machine. They may be placed on the upper floors or the roof without in any way interfering with their operation.

The economy of steam turbines has also been well established and I would cite a few examples of tests on various machines lately taken in the Westinghouse Machine Company's works.

RESULTS OF TESTS ON WESTINGHOUSE PARSONS STEAM TURBINES.

In the tables below are given boiler pressure (b.p.), brake horse power (b.h.p.) or electrical horse power (e.h.p.); total weight of water per hour, and weight of water per electrical or brake horse power.

400 K. W. 135 B. P. 27″ Vacuum.

B P	Vacuum	B H P.	Total Lbs. Water	Water Rate.
137.6	27	64.6	9319	14.92
136.0	27	56.2	7852	15.21
138.0	27	90.7	6236	15.96
144.0	27	6.3	764	.....

400 K. W. 135 B. P. 26″ Vacuum.

B P	Vacuum	B. H P	Total Lbs. Water.	Water Rate.
143	26	623.4	9502	15.24
144	26	508.2	7992	15.73
144	26	381.0	6211	16.56
138	26	10.7	1035	.....

400 K. W. 155 B. P. 100° Superheat. 28″ Vacuum.

B P.	Superheat	Vacuum	K W.	E H. P	Total Lbs. Water	Water Rate per E H. P.
150.4	99.6	28.150	412.50	553.00	7498	13.55
152.6	102.3	28.123	312.80	419.30	5797	13.83
152.6	102.0	28.200	209.70	281.07	4140	14.73
152.0	58.6	28.200	113.35	151.95	2745	18.06

1000 K. W. 150 B. P. 28″ Vacuum. Moist Steam.

B. P	Moisture	Vacuum	K W	E H P	Total Lbs. Water	Water Rate per E H P
140.2	2.3	28.36	961	1288.1	20251.0	15.70
140.3	2.0	28.33	756	1015.0	16617.0	16.35
145.0	1.6	28.30	481	645.0	11903.6	18.45
145.0	1.8	28.48	250	3355.0	7656.0	22.80

1500 K. W. High Vacuum.

B. P.	Per cent. Moisture.	Vacuum.	K. W.	E. H. P.	Total Lbs Water.	Water Rate per E. H P
148.8	1.2	27.92	1545	2065	30456	14.73
149.9	2.5	28.12	935	1252	19703	15.75
151.8	2.1	28.98	262	349.0	7392	21.80

Same Machine.

B. P	Superheat	Vacuum	K W.	E. H P.	Total Lbs. Water.	Water Rate per E. H. P
154.6	140.6	28.10	1512.0	2030	25686.0	12.66
149.5	138.9	28.04	904.0	1210	17042.8	14.10
148.9	138.4	28.20	306.2	412	8108.6	19.68

Turbines of the type mentioned above being very simple affairs require but little erection, and it is a simple matter for them to be thoroughly tested in the builder's works.

The advent of the steam turbine in large central stations will probably involve some changes of detail in the auxiliaries. The gains in economy due to operating with high vacuum demands a higher type of condenser than those ordinarily employed. The fact of the turbine being able to avail itself of all the advantages of superheat while exhibiting none of its disadvantages will usually make the consideration of superheaters desirable. A steam turbine is more economical than a reciprocating engine principally because it is able to make use of the expansive energy of steam down to lower limits than is practicable with reciprocating engines. The comparatively low friction losses of a turbine enables it to hold up its high economy over a wider range of load than is possible with a reciprocating engine.

The demand for high class condensers is met by the employment of surface condensers equipped with tandem cylinder rotative dry vacuum pumps for dealing with the air, and a small duplex independent pump for dealing with the water. This latter pump delivers into the hot-well from whence the feed pumps draw their water, which may be a sealed chamber, such that the steam, from leaving the boilers, to being returned to them as feed water, never comes into contact with the air and does not become ærated, thus leaving the air pump little to do except taking care of a small unavoidable leak in the exhaust piping.

To make a comparison of the effect of vacuum, a test on a 1500 k.w. turbine shows the following:

25″ Vacuum = 16.5 lbs. per Electrical H.P. Hour.
26″ " = 15.8 " " " " "
27″ " = 15.3 " " " " "
28″ " = 14.8 " " " " "

with 150 lbs. boiler pressure. Moist steam.

The effect of superheat is to increase the economy not less than 7 per cent. for 50° superheat, 10 per cent. for 100° superheat, and 12½ per cent. for 150° superheat.

What will be the limits of superheat that may be employed is hard to determine, but I imagine the limit will be reached in the superheater itself as soon as in the turbine.

The reason why superheat makes such material gain in economy is probably because it reduces the amount of water in the expanded steam due to adiabatic expansion.

It is also probable that the heat added to the steam in the shape of superheat is nearly all available for useful energy, which is not the case of the heat used in evaporating the water in the boiler, as but a small percentage of the latent heat is given up in the shape of energy in an engine. There is no doubt that the cost of attendance and oil with turbines will be much less than with reciprocating engines, and there is little doubt that steam turbines will continue to be employed more and more.

In reply to questions by Mr. James and Mr. Lincoln, Mr. Hodgkinson gave the following information.

Turbines of the Parsons type built by the Westinghouse Machine Company do not lend themselves well to design in very small powers. For that reason machines less than 200 or 300 k.w. are not encouraged. For sizes larger than that the steam consumption may generally be said to decrease with the size.

For driving electrical machines, in which the number of poles and standard frequencies are of such nature that the number of poles being very few, the intervals between standard speeds are very large. For instance, with standard frequency of 60 cycles there is no intermediate speed between 3600 and 1800 r.p.m. With other periods, such as 25 cycles, which is used for power work exclusively, we cannot get higher speeds than 1500, which requires a two-pole generator. It thus happens in the design of turbines we get uncomfortable speeds.

MR. ETHERIDGE:—One of Mr. Lardner's remarks did not favorably impress me:

"Frequently the business in the individual towns would not be large enough to permit of an independent plant in each, and any risk of interruption to service is put up with because it is the best kind of service that such a community can support."

That seems to me to be a reflection on the electrical engineer. I do not see why a small town should not have just as good service as a large city. It is a question only of the proper construction of transmission lines; a matter thoroughly discussed at the last meeting of the INSTITUTE.

MR. RICE:—Mr. Rice spoke of the experience he had had in central station work when connected with the New York Edison Company. He spoke of the excellent record of the New York Edison Company for continuity of service, as in twelve years' time current had never been entirely off their circuits. Mr. Rice stated that in his judgment the direct current possessed many

advantages over alternating current for distribution in a large city. The two most important advantages are that it permits the use of storage batteries and under certain conditions is better for operating motors. In all of the large cities the storage battery is used not so much as a means for carrying the peak of the load as an insurance against shut down. Central stations in all of the large cities are supplied with storage batteries of sufficient size to carry the entire load for short periods without assistance from the generating apparatus.

A case was cited where seven 1,000,000 c.m. cables were burned off on account of a short-circuit, and the chart at the station showed a variation of but 1½ volts, thus showing the great steadying effect of the storage battery on the system.

As soon as one leaves the central station he gets into the mesh system of conductors, so that in case of trouble there is relief from every direction. At frequent intervals in New York City there are generating stations or rotary substations having storage batteries of large capacity. This insures absolute continuity of service.

The conditions essential to the obtaining of a high load factor was referred to. Attention was called to the methods of Mr. P. G. Gossler of Montreal, who by granting special rates on power at certain times of the day had created a large demand for power between 4 A.M. and 4 P. M., thus obtaining an extremely high load factor.

The importance of safety devices for maintaining continuity of service was also referred to.

MR. LINCOLN:—In confirmation of Mr. Rice's statements in regard to batteries, I was talking some weeks ago with one of the New York Edison Company's engineers, during which conversation he stated that his company's aim was never to have the batteries discharged. They were kept practically full all the time, so that in case of accident to the generating machinery, the batteries would be prepared to take the load. The batteries are used practically as safety devices, rather than to reduce the load on the generating station, for which purpose batterries are very often used.

Another point, and one which Mr. Rice did not bring out, is the fear on the part of the operators of large low-tension systems, such as the one in New York, is that if power ever does get off the mains, it will be very difficult, if not impossible, to get it back on. The net-work of mains is fed by some ten or fifteen different substations. A single substation would not begin to be able to carry the load and it would be practically impossible to have all the substations thrown into the system simultaneously.

The engineer to whom I was talking cited a case in Milan, where there is also a large low-tension network. In this case he said that the power went off his network and the difficulty, as noted above, was experienced in getting the power back on to the network. It was necessary finally to cut the network up into

sections, and this cutting up of the network required nearly three days. The power was off of parts for all that time. This is one of the dangers to which a large low-tension system is liable and is what the New York Edison Company is striving to avoid by keeping their batteries prepared at all times to assume the total load independent of any generating system.

MR. SCOTT:—I take exception to the broad statement that "the way to maintain continuity of service is to have safety devices"—there may be too many. I know of a large company which installed a great many safety devices and had troubles at various times. After the plant had been running for some four or five years, I made a remark one day to the engineer in charge that most of their troubles had been due to their safety devices. Although the safety device is intended to prevent accidents, it is itself often the very source of accident and of trouble. This is one of the reasons why the fuses have been left out between alternators and bus bars. Fuses, particularly for high voltage or for heavy current, are disagreeable adjuncts to a station equipment. In general it is not good practice to put in a line anything that can be avoided.

Meeting adjourned.

DISCUSSION AT ST. LOUIS, MAY 16, 1903.

The meeting was called to order at 8.30 P. M., at the Engineers' Club, W. E. Goldsborough, Chairman, presiding.

Announcement was made by Secretary Swope of Mr. Carnegie's gift of $1,000,000 to the Associated National Engineering Societies. The Secretary spoke of a local movement for the same object. Mr. Goldsborough made some remarks in regard to the same matter, also in regard to the INSTITUTE Building and the better standing it would give to the profession of engineering throughout the country.

Announcement for the next meeting was then made, also for the annual meeting at Niagara.

The papers for the evening were:

No. 1.—"Economical and Safe Limits in Size of Central Stations," read by Mr. Dyer.

No. 2.—"Safety Devices in Central Stations and Substations," read by Mr. Langsdorf.

No. 3.—"Multiple versus Independent Operation of Units and Central Stations," read by Mr. Klauder.

The salient points of the discussion at the New York meeting were read by the Secretary.

The papers were then opened for discussion, in which Mr. E. D. Matlack participated, whose company is now installing a 500 kilowatt General Electric generator, connected to a Curtis turbine. Much discussion was brought out in regard to the question of the advantage of superheating the steam.

Mr. Borden spoke at length on the same subject.

Mr. Welz, Director of the Word's Fair, told of waste heat engines, which have been largely advanced in Germany, but not used in this country. He said:

I should like to draw your attention to some new features of modern development of central stations brought out in Germany. When in Berlin last September, I visited the central stations in Markgrafenstrasse where a new type of engine, a so-called "sulphurous anhydride waste-heat engine," was running. The reason for the construction of these machines was the low thermal efficiency of the steam engine which is, in the best machines, only about 23 per cent. The purpose of the waste-heat engine is to use the heat which is generally lost in the exhaust steam for vaporizing a liquid with a low boiling point of which the vapors under the given temperature have already a very high pressure. With these vapors a new engine can be driven. Of all the liquids which can be employed for this process, the sulphurous anhydride (SO_2) has proved to be the most practical.

The general scheme of the engines is very simple. The exhaust steam of the steam engine is conducted through a surface condenser which serves as a vaporizer of the SO_2 liquid. At a temperature of 150° F., corresponding to the temperature of steam in an 80 per cent. vacuum, the sulphur dioxide vapors have a pressure of 156.5 lbs. per sq. in. abs. These vapors then enter the waste-heat engine, which is similar in construction to a steam engine. The sulphur dioxide vapor leaves the engine at a pressure of 4.8 lbs. per sq. in. abs. and passes on to a second surface condenser, where, by means of circulating water, it is again liquified. A small pump delivers the liquid sulphur dioxide from the condenser back into the evaporator or the exhaust-steam condenser, where it is ready to repeat the cycle. Hence, neglecting the losses through possible leakage, the working medium is used over and over again and requires no replenishing. The only difficulty in the construction of these machines was to have the stuffing box of the piston-rod tight. After some experiments this difficulty was entirely overcome and Prof. Josse, the constructor of the machines assured me, when I saw him in Berlin, that the machines as now constructed are perfectly satisfactory. The waste-heat engine in the Markgrafenstrasse develops 175 h.p., using the exhaust steam of a 360 h.p. vertical compound steam engine, and thus adds 48.6 per cent. to the energy produced by the steam engine. The cost for such a waste-heat engine is about equal to that of a steam engine of the same size. It is therefore easily seen that in this way the efficiency of electric central stations can be largely increased.

At the present time there are a great number of such waste-heat engines in use or under construction; as an example of the modern construction of these machines, I can show you a picture of a 200 h.p. and a 450 h.p. waste-heat engine the first built by the Maschinenfabrik Sulzer the latter by the Goerlitzer Maschinenbauanstalt. The waste-heat engines for the utilization of

exhaust steam are now entirely worked out as turbines as well as piston engines. Trials have been made lately for the utilization of flue gases of boilers, blast furnace gases, exhaust gas of gas-engines, etc., and these trials give satisfactory results, but the company which exploits these patents is not yet ready to put the machines on the market.

I should like to show you a very interesting diagram; you see here upon the upper side of the drawing the general disposition of a steam plant: boiler, steam engine and waste-heat engine; the diagram below shows in per cent. of the heat energy produced in the boiler the amount of energy developed in the steam engine and in the waste-heat engine and the losses which occur during this process. According to this, 12 per cent. of the original heat is utilized in the steam engine and 4 per cent. in the waste-heat engine; 2 per cent. is lost in the ashes, 7 per cent. by radiation from the boiler, 22 per cent. goes in the flue gases, where 6 per cent. is recovered by the economizer and 16 per cent. escapes through the chimney, 2 per cent. is lost in the piping from the boiler to the steam engine, 2 per cent. radiated from the steam engine, 1½ per cent. in the steam piping to the vaporizer and 53½ per cent. is lost in the cooling water.

DISCUSSION AT PHILADELPHIA, May 11, 1903.

CHAIRMAN HERING:—The papers are now open for general discussion.

MR. WM. C. L. EGLIN:—There are one or two points on which I differ with Mr. Torchio, particularly on the question of opening both the oil-switches in series. It seems to me it would be much better to open first one switch and if that fails open the second, for the reason that the arc introduced by the failure of the first switch will very materially reduce the load to be opened by the second switch. It is possible, in opening both together, that both might explode and form an arc which, of course, could not be put out under many conditions without shutting down the generator.

Mr. Lardner speaks of large versus small stations. I cannot agree in any way with the author of this paper in connection with stations for light and power. In the first place the location of the central station is perhaps the most important single feature of the system. A desirable or a perfect location is

extremely hard to get in any large city, and it is becoming more difficult every year. At first it was generally supposed we could go any distance with a high tension station, but that is not true. You must be reasonably close to your load center, especially if you expect to use underground distribution or transmission. You have to depend on water facilities, coal facilities and railroad facilities. To take care of the requirements of such a station, you need an area of greater length than the ordinary city block; that is, you need a station which can be extended in length for future requirements without being cut up by streets. In my opinion it is essential that the entire equipment of a central station of this kind should be on parallel lines; that is to say, the boiler room, the engine room, engine room equipment, steam piping equipment, coal apparatus and switchboard apparatus should be in parallel lines, so that every lineal foot will give one lineal foot for additional requirements. That means that the station will be narrow and long. The station that the Philadelphia company has started and completed—the first section—has possibly a growth of fourteen hundred feet in length. That is possibly double the length of any other station talked of, although it will only have a little more capacity in that length than some of the other stations.

The location of the substation is not at all as important as the generating station, for the reason that you have only one or two things to consider—one or two classes of apparatus to be considered. In the substation you may say you want only the electrical machinery. In Mr. Junkerfeld's division of the cost of real estate and generating apparatus in the central station he gives it as 35 to 45 per cent. That is probably a little high; but even at 30 per cent., that would represent several millions of dollars, in a large city. The transmission system is from 3 to 6 per cent., and the substations, including real estate, from 10 to 15 per cent.; so that the substation cost is small and it is divided into a large number of units. The substation can be placed in almost any kind of building.

The point in turbines versus engines that seems to have escaped the attention of the authors is the light load efficiency. It is well known that the steam engine efficiency is greatest at from 80 to 100 per cent. of the full-load. With a turbine the light load efficiency is very high. In the maximum there is very little difference between half-load and full-load, and even a very high efficiency on a quarter-load. This makes the actual efficiency of the plant very much higher than with steam engines.

The question of storage-batteries as auxiliaries depends entirely on the conditions of the service. Where maximum reliability and continuity of service are not necessary, a storage-battery can be omitted. In the case of the substation feeding into a low-tension network, as in the Edison station, a storage-battery is just as essential as the converter or any other part of the equipment of the substation. In the event of an accident in which part of the load is thrown off, the part of the load lost from-

the substation is transferred to the next substation, making trouble at that point. The storage-battery will tide these difficulties over, and in a system where continuity of service is of the first consideration, I believe that the engineer should invariably specify a certain proportion of storage-battery.

MR. HORATIO A. FOSTER:—It seems to me the original subject that was set before this meeting has been somewhat changed. As I remember, the subject was to be the tendency of the development of the modern central station. It seems to me that this might be called a discussion of the central station in very large cities, which of course is very important. I might say a little something about the tendency of the development in the smaller stations in the hundreds of towns outside of the large cities, which I think is quite as important as that in the large cities. Of course in the large cities also we have another point, and that is the difficulty of defining a central station. We have many plants in the larger buildings which are substantially central stations in themselves, plants that deliver a current to a large and wide area far ahead of the current delivered in many of the large central stations, so-called.

Another point that I hardly think has been given due consideration is a comparison of the cost of current in any of these large cities. Take New York City, for instance, they are comparing the cost delivered from the new station with the cost delivered from stations they had previously, and not with the cost of the separate stations. I would like to learn the cost of current delivered to the lamp or to the mains or to the railway network as developed by the modern style of single station. With the large amount of high-tension cable, costly conduit, and costly distribution in every way, as compared with that of a duplication of stations; that is, of a few good large stations which are located nearer the centres of distribution and therefore eliminate most of the costly distribution.

CHAIRMAN HERING:—I am pleased to hear what a number of the speakers had to say about the advantages of motor generators over rotary converters, because about two and a half years ago, in a paper read before the INSTITUTE, I called attention to this, but it intimated then that I was not at all in fashion, and that the rotary was the only proper thing to use. It seems now, however, that this fashion has changed. I often think there is altogether too much fashion in such matters, particularly in this country where we are too apt to follow the leaders blindly.

Mr. Lardner says the direct current dynamos are ruled out by the use of turbines. It seems to me he is not quite right in this; just as the turbine is the ideal engine, so the unipolar machine is an ideal continuous current dynamo, and the two seem to go well together. Unipolar machines have never been developed like the others, but that is no reason why they never will be, now that the very high speed turbine exists. The difficulty seems to lie in leading the current off from the edge of a disc which has an enormously high peripheral velocity.

MR. HEWITT:—There is one point I forgot to speak of when on my feet before and that is the possibility of offsetting the economies of a station by arranging it in a disadvantageous way, or by placing in too many auxiliaries. In two stations with which I am familiar—one a non-condensing station and the other a condensing, with equal loads, the cost per k.w. hour is almost identical. The entire economy gained by condensing in one case is offset by the fact that it requires enough additional men to offset the saving in coal; so that the cost per kilowatt hour is the same. If you place auxiliaries in the basement or in out-of-the-way places you have got to have some man to operate them. For traction work, anyhow, I can speak positively that the simpler the station is in all its parts the cheaper it will be to operate.

MR. TORCHIO:—I believe that the only direct question in reference to my paper was the opinion expressed by Mr. Eglin. that it was desirable not to open the two switches in series at the same time, reserving the second switch for hand operation, in case the first is blown up, as the arc would reduce the current in the short circuit. I differ with Mr. Eglin. I think where the first switch blows up and the arc is maintained across the metal of the oil-can, the resistance of the arc will make practically no difference in the amount of current in the short circuit, and if it is necessary to open the second switch by hand, it might just as well open in the first place.

Although not bearing directly on my paper, I want, while I am speaking, to take issue to the statement made about the undesirability of one central generating station in New York, in the case of the lighting company. The lighting company was a few years ago operating several low-tension stations throughout the city, but when it came to the point of extending them they found difficulties in the cost of real estate, in not being able to obtain condensing water, in the question of operating steam stations in partly residential or business sections on account of complaints of neighbors objecting to noise, smoke, ashes, etc. To locate a direct current station along the water front was practically an impossibility, on account of local conditions, the water front being one mile or over a mile away from the centre of heavy distribution. The operation of several stations would also have added to the cost of operations and also materially to the amount of taxes which the company would have been liable for, and other reasons.

The whole question, of course, boils down to the point that we want to deliver one kilowatt to the customer for the least cost, but in this cost we must include all items of expense, besides the purely production cost. I believe, however, that people not closely familiar with the development of these stations, have wrong impressions about the relative importance of the different factors entering into the problem, and it seems, from the remarks I often hear, that undue prominence is given to certain

features of the system, and amount of losses and efficiency, and also cost of transmission cables and transforming apparatus. For instance, Mr. Hewitt to-night placed emphasis on the high cost of installation for high-tension cables. In paper-insulated cables as generally used the cost of paper bears a small proportion to the total cost of the cables.

In this discussion of multiplicity of stations I do not really follow the idea of the gentlemen advocating several low-tension stations. If they mean that these stations have to supply separate districts, it seems to me that if something serious happened to one station it will leave that district without light. That the large direct current stations are open to the criticism of breaking down, has been proved by several shut-downs of large stations due to short circuits, fires, bursting of steam pipes, or other reasons, so that in a measure the criticisms made to one alternating current station applies also to the independent stations.

As to the statement of Mr. Foster that rotary converters are the source of numerous troubles, I believe he qualified the statement when he said that it applies to high frequency rotaries. In all our experience with 25-cycle rotaries we have not found this type of apparatus to be more troublesome to operate than similar direct current apparatus.

Mr. Foster has stated that in large cities the development of power service is somewhat handicapped on account of the Underwriters imposing heavy restrictions to the installation of proper pumping apparatus which cannot be obtained from electric driven pumps. I think that the electric pump can be operated as satisfactorily as a steam pump, and this has been conclusively proved by the extensive use of electric pumping in the California plants, where they do extensive pumping with practically very little attention to the apparatus. The fact that in New York City there are from sixty to seventy thousand horse power for a great variety of commercial uses proves that the central stations are not very much handicapped in securing power customers.

Motor generators sets have been referred to. I imagine that the speakers had reference to induction motor generator sets, not synchronous motor generator sets. As I said before, I do not find any reason to pay more for this apparatus when you can get just as satisfactory results from rotary converters, as the latter is about 25% cheaper than the motor generator sets, and the efficiency is higher.

About the steam turbines with d.c. unipolar machines, I do not believe that this type of apparatus would be applicable in large cities, for many reasons. The unipolar machines are not capable of being designed for large quantities and commercially high-voltages. As far as my experience goes with the unipolar machines I find that it is very difficult to get rid of the heat.

requiring forced ventilation, also it is difficult to collect the current by ordinary brushes. The fact also that the units would be of small capacity would be a handicap to the use of unipolar generators as I think that the steam turbine in small sizes does not bear the same economical advantages to the reciprocating engine as the large steam turbine compared with a large engine. When there will be a more complete line of development in steam turbines most probably the cost will diminish, but at present the small steam turbine does not hold the relative economical advantages compared with the reciprocating engines as in the case of large turbines.

MR. PAUL SPENCER:—I was interested in the remarks of Mr. Hewitt and Mr. Foster, particularly in what they had to say in regard to the advantages of a number of stations as compared with one large station. It seems to me that these papers read to-night were written particularly on New York plants, and the engineering features therein described, while perfectly applicable to the New York situation, do not necessarily bear on the development of central stations throughout the country. There is some danger, I think, in engineers throughout the country being very largely influenced by what is done in situations like New York, and in adopting what is done there for stations where the practice would not fit conditions so well. We are rather apt to follow fads and fashions, and an engineer, in laying out a station, likes to have the latest and most up-to-date appliances. In the smaller and more extended situations, I would agree with Mr. Hewitt and Mr. Foster, that more than one station generating at the service and voltage to be distributed would in many cases be cheaper in first cost and more economical in operation than one large station from which the current would have to be transmitted and converted before being distributed.

MR. HEWITT:—Perhaps I did not make myself clear in regard to the cost of cable. What I had in mind was in the ground return we eliminate one cable altogether, or at most use a piece of bare copper; so that in estimating the cost of high-tension cables for conduit work, as I stated before, the figures I have made showing the cost of the extra cable, will offset the saving in copper for moderate distances.

In regard to the duplication of stations—I should have stated that of course it is taken for granted that these stations will be connected by ample tie lines. On the map the blue wafers represent the Philadelphia Rapid Transit Company's plants. They are all connected together, either directly or indirectly by tie line cables, so that it is possible to shift the load from the lower part of the city out as far as Ogontz, if necessary. The red ones are the lighting stations, and the green represent stations that do not belong to the Rapid Transit Company.

MR. TORCHIO:—Do the tie lines transmit the full output of the station?

MR. HEWITT:—It might be so arranged. In this particular case it would not be so, although it is possible to shut down any particular one of the stations without affecting the cars to any great extent, because the more important stations have two and some as high as four different tie lines. One station, for instance, in the centre of the city is connected directly to four other stations and indirectly to a fifth one.

MR. TORCHIO:—The remark I made when I was reading my paper is this: it must not be understood that the people in New York do not appreciate that conditions will determine the best lay-out to be made, and I wish to state that the same engineers that have had to do the designing in the lighting plants in New York have also been advising the traction company where they have used direct current machines to have them install large current machines of three thousand kilowatts. There are quite a number in the same station along side of alternating current machines, and also they added in existing stations large direct current units. That was only because the conditions allowed. They had plenty of facilities for coal, and in other distributions it makes that condition like Philadelphia.

BRANCH DISCUSSIONS.

Discussion at Minneapolis, May 1, 1903.

The Minnesota Branch of the Institute held their 12th regular meeting in the Electrical Building at the State University May 1st. Attendance 22.

The papers on Central Stations by Messrs. Lardner, Junkersfeld and Torchio were read and discussed.

It was stated in Mr. Junkersfeld's paper that the feeders and mains, cables, conduit and Edison tubes require 40 to 48 per cent. of the total investment. Suggestions were made that this investment would be greatly reduced by the use of a higher local distributing voltage, 220–440 volts. The alternating current system throughout, doing away with the rotary converter and substations, was commended because of the smaller investment, lower cost of operation and the decidedly better regulation. Unfortunately, our larger cities now use direct current for local distribution and use direct current arc lamps and motors. In smaller cities, where an alternating current local distribution is used, the decreased cost of distribution and operation, and the better regulation are well known.

A reasonable amount of sectionalizing is considered advisable. Plants and large generating units are now designed to be operated separately whenever it is so desired. But normally, multiple operation of all units and of separated power plants is always advantageous. The total shutdown of a system would not occur when the time limit overload devices are perfectly proportioned.

Referring to Mr. Lardner's paper, the fact that the steam turbine has a relatively high efficiency at light loads commends it to us especially for heavy electric railway work. Here the load factor is very low and the power required fluctuates between wide limits.

The advantages of two large stations of say 5,000 k.w. capacity each, compared with a single station of twice that capacity is recognized for long-distance heavy electric railways as well as for other services. The saving on real estate and installation with one station would be small. The difference in economy of fuel and labor, per k.w. hour delivered to the electric motors, would be very small. The two stations being connected by high voltage transmission lines would operate in multiple and the disabling of part or the whole of one station would leave the railway with a relatively larger available power.

A heavy freight and passenger electric railway, 150 to 500 miles long, should not depend upon one electric power plant. Two or more are preferable. The steam locomotive has fewer links between the coal and the application of power to the wheels and is an example of the present ideas of steam railway companies regarding "The *economical* and *safe* limits in the size of stations."

The electric power plant has a great many links to decrease the reliability of service, which is paramount. The use of two 5,000 k.w. plants, separated 100 miles, would in general give a more safe and reliable design than one 10,000 k.w. plant. We must look at this problem from the standpoint of reliability of service, rather than from the standpoint of economy.

By increasing the number of stations the greater refinement in the one station, brought out in Mr. Torchio's paper, will seldom be required.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 19, 1903.

The 177th meeting was held this date at 12 West 31st Street.

President Charles F. Scott called the meeting to order at 8:25 P.M. and said:

This is our annual meeting for the transaction of Institute business. Proxies have been received and a Proxy Committee will now be appointed whose functions will be to look over and check up the list of proxies. The Secretary has tabulated these so that the duties of the Committee will be light. I will appoint as such Committee Messrs. Lardner, Nicholson and Walker. The Secretary will give a report of the elections held in the Board of Directors this afternoon for transfers from associate to full membership.

As provided in the Constitution, the Board of Directors makes a report of the progress of the INSTITUTE during the year and of its financial affairs to the INSTITUTE at this time. The report is printed on long sheets which are now being passed about the room. This report gives a summary of the year's work of the INSTITUTE as conducted under the different committees. The report contains a reference to the development of our work through local organizations, of which some 21 are now organized. It calls attention to the fact that the increase in the membership is 44 per cent. during the fiscal year ended May 1st. The financial report shows the INSTITUTE to be in a healthy condition. We manage to keep a small margin ahead, although the increased activities of the year in the publishing of transactions, in the publication of the monthly bulletins, and in the various operations of the committees and conduct of local organizations has materially increased the expenses. The INSTITUTE has a cash value, so to express it, of some $40,000. Most of that is in the form of the library and bonds and accounts receivable.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1903.

The Board of Directors presents herewith for the information of the INSTITUTE a report of its work during the past year, also of the financial standing of the organization.

The Annual Convention for 1902 was held at Great Barrington, Mass., June 18–22, and was generally considered the most successful ever held by the INSTITUTE, about 250 members being in attendance. The revised Standardization Report was approved by this Convention, and subsequently printed in the Transactions.

The INSTITUTE has prospered during the year; work along its established lines has been successful, and several new departments of activity have been developed. The work of the INSTITUTE is in large measure delegated to committees reporting to the Board of Direction. A brief statement regarding the work of the several standing committees and of the more important special committees affords a general view of the scope and character of the work of the INSTITUTE.

At the September meeting of the Board several of the Standing Committees were reconstituted by appointment of the incoming President.

Committee on Finance.—This Committee has kept careful guard on the finances of the INSTITUTE. At the beginning of the year it made estimates of income and obtained from the several officers and committees estimates of their probable expenses, and appropriations were then made to meet the coming demands.

Library Committee.—The Library has received numerous accessions and the work of binding, arranging and cataloguing has received due attention. The additional room available beginning at the present time will relieve the congested condition of the Library.

Committee on Papers.—This Committee has followed the plan pursued by the preceding Committee, in providing several papers upon one topic for each meeting.

Editing Committee.—This Committee finds that the increased quantity of material has made necessary the division of the bound Transactions into semi-annual instead of annual volumes. The discussions of the branch meetings add to the volume of material and to the labors of the Editing Committee. When discussions upon the same papers take place at the different branches, the same ideas are in many cases repeated, making a careful revision of the discussions necessary in order to prevent repetition while retaining all that is new and valuable.

Board of Examiners.—This Board has found the volume of its work increased owing to the larger number of applications for admission to the INSTITUTE and for transfer to full membership. During the year it has recommended 825 candidates for election to the grade of Associate and 30 Associates have been recommended for transfer.

Committee on Standardization.—The membership of this Committee was almost entirely reconstituted at the beginning of the year. The new Committee has taken up the matter of a revision of Sections 43 and 71 of the Standardization Report adopted June 20, 1902, also the extension of the Table of Sparking Distances, the Standardization of Switchboards and Materials, and the Standardization of Nomenclature.

Committee on National Electric Code.—This Committee largely reconstituted at the beginning of the year, has performed very important service in modifying the proposed rules of the National Association of Fire Underwriters with regard to high-tension circuits. The final report of the Committee has received the approval of most of the important national electrical associations, including the National Electric Light Association, the Pacific Coast Transmission Association, the Northwestern Electrical Association, and the Association of Edison Illuminating Companies.

Committee on Local Organization.—This Committee was appointed at the beginning of the year for promoting the organization of local meetings for an extension of the work of the INSTITUTE. The Committee arranged its plans in harmony with the general methods and purposes of the INSTITUTE, and announced general plans for the inauguration of meetings without much formality of organization. Local branches have been formed in several cities, and also in a number of Universities and Technical schools, in some cases under the direct supervision of the Instructor and in other cases in connection with an engineering society among the students. Local branches among INSTITUTE members are in some places conducted independently of other organizations; in other cases they are held in connection with a local engineering club or society. During the year local branches have been organized at the following places:

Allegheny, Pa. [Western University of Pennsylvania]; Ames, Iowa [Iowa State College]; Bethlehem, Pa. [Lehigh University]; Boston, Mass. [Massachusetts Institute of Technology and local members]; Cincinnati, Ohio; Columbia, Mo. [University of Missouri]; Columbus, Ohio [Ohio State University]; Denver, Colo.; Ithaca, N.Y. [Cornell University]; Lafayette, Ind. [Purdue University]; Madison, Wis. [University of Wisconsin]; Philadelphia, Pa.; Pittsburg, Pa.; Schenectady, N Y. [Union University and local members]; St. Louis, Mo.; State College, Pa. [Pennsylvania State College]; Urbana, Ill. [University of Illinois]; Washington, D. C. [Columbian University and local members].

The local organizations in Chicago and in Minneapolis, the latter in connection with the University of Minnesota, which have been in existence for some time, have taken on renewed activity during the present year. The weak point in national organization which has long been recognized, is the inability of a scattered membership to participate in society meetings. This difficulty has been in large measure overcome by establishing local branch meetings at which the papers and discussions presented at the general meeting in New York are read in the various local branches. The result of the local branches as a stimulus to the growth of membership, is shown by the following table:

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1903.

The Board of Directors presents herewith for the information of the INSTITUTE a report of its work during the past year, also of the financial standing of the organization.

The Annual Convention for 1902 was held at Great Barrington, Mass., June 18–22, and was generally considered the most successful ever held by the INSTITUTE, about 250 members being in attendance. The revised Standardization Report was approved by this Convention, and subsequently printed in the Transactions.

The INSTITUTE has prospered during the year; work along its established lines has been successful, and several new departments of activity have been developed. The work of the INSTITUTE is in large measure delegated to committees reporting to the Board of Direction. A brief statement regarding the work of the several standing committees and of the more important special committees affords a general view of the scope and character of the work of the INSTITUTE.

At the September meeting of the Board several of the Standing Committees were reconstituted by appointment of the incoming President.

Committee on Finance.—This Committee has kept careful guard on the finances of the INSTITUTE. At the beginning of the year it made estimates of income and obtained from the several officers and committees estimates of their probable expenses, and appropriations were then made to meet the coming demands.

Library Committee.—The Library has received numerous accessions and the work of binding, arranging and cataloguing has received due attention. The additional room available beginning at the present time will relieve the congested condition of the Library.

Committee on Papers.—This Committee has followed the plan pursued by the preceding Committee, in providing several papers upon one topic for each meeting.

Editing Committee.—This Committee finds that the increased quantity of material has made necessary the division of the bound Transactions into semi-annual instead of annual volumes. The discussions of the branch meetings add to the volume of material and to the labors of the Editing Committee. When discussions upon the same papers take place at the different branches, the same ideas are in many cases repeated, making a careful revision of the discussions necessary in order to prevent repetition while retaining all that is new and valuable.

Board of Examiners.—This Board has found the volume of its work increased owing to the larger number of applications for admission to the INSTITUTE and for transfer to full membership. During the year it has recommended 825 candidates for election to the grade of Associate and 30 Associates have been recommended for transfer.

Committee on Standardization.—The membership of this Committee was almost entirely reconstituted at the beginning of the year. The new Committee has taken up the matter of a revision of Sections 43 and 71 of the Standardization Report adopted June 20, 1902, also the extension of the Table of Sparking Distances, the Standardization of Switchboards and Materials, and the Standardization of Nomenclature.

Committee on National Electric Code.—This Committee largely reconstituted at the beginning of the year, has performed very important service in modifying the proposed rules of the National Association of Fire Underwriters with regard to high-tension circuits. The final report of the Committee has received the approval of most of the important national electrical associations, including the National Electric Light Association, the Pacific Coast Transmission Association, the Northwestern Electrical Association, and the Association of Edison Illuminating Companies.

Committee on Local Organization.—This Committee was appointed at the beginning of the year for promoting the organization of local meetings for an extension of the work of the INSTITUTE. The Committee arranged its plans in harmony with the general methods and purposes of the INSTITUTE, and announced general plans for the inauguration of meetings without much formality of organization. Local branches have been formed in several cities, and also in a number of Universities and Technical schools, in some cases under the direct supervision of the Instructor and in other cases in connection with an engineering society among the students. Local branches among INSTITUTE members are in some places conducted independently of other organizations; in other cases they are held in connection with a local engineering club or society. During the year local branches have been organized at the following places:

Allegheny, Pa. [Western University of Pennsylvania]; Ames, Iowa [Iowa State College]; Bethlehem, Pa. [Lehigh University]; Boston, Mass. [Massachusetts Institute of Technology and local members]; Cincinnati, Ohio; Columbia, Mo. [University of Missouri]; Columbus, Ohio [Ohio State University]; Denver, Colo.; Ithaca, N.Y. [Cornell University]; Lafayette, Ind. [Purdue University]; Madison, Wis. [University of Wisconsin]; Philadelphia, Pa.; Pittsburg, Pa.; Schenectady, N Y. [Union University and local members]; St. Louis, Mo.; State College, Pa. [Pennsylvania State College]; Urbana, Ill. [University of Illinois]; Washington, D. C. [Columbian University and local members].

The local organizations in Chicago and in Minneapolis, the latter in connection with the University of Minnesota, which have been in existence for some time, have taken on renewed activity during the present year. The weak point in national organization which has long been recognized, is the inability of a scattered membership to participate in society meetings. This difficulty has been in large measure overcome by establishing local branch meetings at which the papers and discussions presented at the general meeting in New York are read in the various local branches. The result of the local branches as a stimulus to the growth of membership, is shown by the following table:

	Membership Nov. 1, 1902	Membership and applications now on file, 1903	Gain.
Chicago	85	139	54
Pittsburg	63	115	52
Philadelphia	65	84	19
Boston	75	164	89
Denver	6	30	24
Cincinnati	19	44	25
Schenectady	54	105	51
Columbus, Ohio	6	15	9
St. Louis	18	41	23
	391	737	346

Students of the Institute.—Closely related to the work of the local branches is the action of the Board of Directors, granting privileges to students who are pursuing electrical studies by which they may obtain the monthly Transactions of the INSTITUTE and other privileges at small expense.

Committee on *Theses.*—The Board of Directors by resolution invites the heads of the electrical engineering departments in educational institutions in which local INSTITUTE meetings are held to select the thesis of each year's graduating class that is of superior merit. The theses so submitted are referred to the INSTITUTE Committee on Theses which may select and recommend to the Board for publication those of superior excellence. This will give a stimulus to electrical students and will be a satisfactory means of giving recognition and publicity to that which is of merit.

Committee on Engineering Data.—After careful consideration of the matter, the Board has established a Committee on Engineering Data for the purpose of collecting and publishing data of use in the electrical engineering profession. This Committee is proposed as a permanent Committee and its grade of work will be on a par in its importance and dignity with that of the Committee on Standardization.

Transmission Committee.—This Committee was appointed at the beginning of the year for collecting data respecting the present practice in electric transmission at high voltage, and of presenting a report in such form as to be of immediate value to electrical engineers. In addition to the collection of data this Committee has selected a number of pertinent topics for discussion and has prepared short papers as introductions to general discussions by the members.

Committee on Membership.—This Committee was appointed at the beginning of the year for the puprose of increasing the membership principally through the coöperation of individual members. The Committee has presented to the members from time to time the desirability of bringing together those who may assist the INSTITUTE, as well as those who may profit by being connected with it. The members have acted upon the suggestion of the Committee, and a notable increase in membership is the result.

Committee on Affiliated Societies.—This Committee has been appointed

for investigating the relations which the INSTITUTE should bear to other organizations, such as other electrical bodies, local engineering societies in connection with local branches of the INSTITUTE and other engineering bodies. This Committee enters upon a large field which may be of the greatest importance to the development of the electrical engineering profession.

John Fritz Medal.—The INSTITUTE has coöperated with the other three general engineering societies in the establishment of the John Fritz medal, and in appointing members of the jury for the award of the medal.

Committee on Universal Exposition at St. Louis.—The Board has by the recommendation of a Committee appointed to consider the relations which the INSTITUTE should sustain to the Exposition and the Engineering Congresses to be held in connection therewith, a Committee on Exhibits. This Committee will have under its direction the collection of an historical and evolutionary exhibit. The Board expects to so arrange that the INSTITUTE will take an active part in the Congresses to be held at the time of the Exposition.

Institution of Electrical Engineers.—The invitation of this INSTITUTE to the Institution of Electrical Engineers to visit America in 1904, and participate in a joint meeting, has been accepted. It is expected that arrangements will be made to hold the joint meeting in St. Louis in connection with the Engineering Congresses.

Union Engineering Building.—The Board has received the letter of Mr. Andrew Carnegie stating that he will give to the four national engineering societies—Civil, Mechanical, Mining and Electrical—and the Engineers' Club, one million dollars for a Union Building. The Board at its special meeting on May 7th, adopted resolutions endorsing the project and certain provisional plans of procedure, and appointed a committee to report to the Board the form of resolution which it should adopt in common with other bodies in order to participate in the Union Building. The final action of the Board of Directors and its recommendation to the INSTITUTE is contained in a separate report.

Monthly Announcement.—The meeting notices to members have taken the form of small pamphlets containing statements regarding the general meetings and the meetings of the various local branches. The Announcement also contains a Secretary's Bulletin and statement of the work of the various Committees, also any other matters of general importance. The list of applications for admission is included in the pamphlet. This form of Announcement keeps the members in more intimate relation to the INSTITUTE work, and is believed to be valuable in awakening and sustaining interest therein.

Reception Committee.—The Reception Committee has been in charge of the unofficial dinners which have been enjoyable social features preceding the monthly meetings. The success of the Library Dinner on February 9th is due to the efforts of this Committee.

Institute Headquarters.—Owing to the growth of the Library and the increase of the general work of the INSTITUTE, it has been found necessary to rent additional space, and on May 1st, the entire seventh floor of the White Building, 95 Liberty Street, was leased. Nearly one-half of this will be occupied by the Library and the remainder by the publicatior clerical and other departments.

Membership.—The total membership at the close of last year's report, was 1,549, classified as follows:

Honorary Members		2
Members		405
Associates		1,142
Total May 1, 1902		1,549
Elected prior to May 1, 1902, and since qualified		16
Elected May 1, 1902, to April 30 1903, and qualified		695
Restored to Membership		1
		2 261
Total Deaths	9	
" Resignations	12	
Dropped as delinquents	11	32
Grand total, Apr 30 1903		2,229

The membership Apr. 30, 1903, was classified as follows:

Honorary Members	2
Members	417
Associates	1,810
Total	2,229

A list of Associates elected during the year accompanies this report. The gain in membership during the year is 680, an increase of 44 per cent. As there are now applications pending and Associates elected but not yet qualified to the number of 391, there is an immediate prospective total of 2,620 members.

Associates Elected.—The Associates elected during the year, May 1, 1902, to April 30, 1903, and their present status is as follows:

Qualified and now associates	695
Died before qualification	1
Elections cancelled	1
Not qualified on Apr 30	165
Total elections	865

Resignations.—Resignations have been received and accepted during the year from the following members and associates who were in good standing:

Members.—Brown Ayres, W. E. Geyer, Henry Jackson.

Associates.—Frank Broili, Harry A. Gillis, F. A. Greenwood, A. F. McKissick, H. N. Sweet, Walter Rutherford, H. Schreiter, J. C. Finney, Paul Bonynge.

Deaths.—There have been the following deaths during the year:

Members.—Charles T. Child.

Associates.—Henry Morton, E. Rathenau, W. F. D. Crane, Max T. Steinle, F. J. Folk, E. A. Darling, I. D. Parsons, Sidney H. Short.

Financial Report.—The reports of the Secretary and Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of the receipts and disbursements during the entire year.

FINANCIAL STATEMENT FOR APRIL 30, 1903.

ASSETS AND LIABILITIES.

ASSETS.		*LIABILITIES.*	
Cash	2,006.75	*Library Fund	787.93
U. S. Bonds, Market value	16,285.00	Carnegie Fund	4,643.60
Library	9,436.75	Building Fund	1,100.00
Transactions (volumes)	2,957.50	Compounded Membership Fund.	4,200.00
Office Furniture and Fittings	495.30	Reserve Fund	10,556.68
Badges	154.50	Surplus	19,311.48
Catalogue Type and Cases	125.00		
Congress Books	231.25	*Not including a donation of $1,100 by one member and about $1,000 by another still in the hands of Library Committee.	
Accounts Receivable	8,407.64		
" Secretary's Petty Cash	500.00		
	$40,599.69		$40,599.69

RECEIPTS AND DISBURSEMENTS.

RECEIPTS.		*DISBURSEMENTS*	
Entrance Fees	$ 3,305.00	Stenography	697.60
Current Dues	17,583.95	Stationery and Printing	2,148.15
Past Dues	1,168.47	Postage	1,543.50
Advance Dues	740.59	Express	346.54
Life Membership Fund	600.00	Badges	619.03
Transactions Sales	1,752.24	Expenses General	667.95
" Subscriptions	463.63	Certificates	93.90
Binding	64.63	Office Fittings	239.60
Advertising	1,685.51	Salaries	5,350.41
Electrotyping and Engraving	23.67	Engraving and Electrotyping	1,778.93
Badges	783.50	Publishing Transactions	7,254.16
Congress Books	16.10	Rent	1,688.04
Postage	1.57	Advertising	804.88
Meeting Expenses	5.00	Binding	577.71
Interest	496.36	Meeting Expenses	1,208.43
Library Donation	1,028.23	Branch Meetings	40.65
Library Volumes	242.80	Office Expenses	154.27
Certificates	220.00	Library Expenses	3,994.62
		Library Fixtures	330.00
		Students	21.00
		Balance	621.58
	$30,181.25		$30,181.25

The total receipts for 1903, exclusive of donations to Library Fund, were in excess of 1902	$8,497.83	
The total disbursements for 1903, were in excess of 1902	9,262.61	
Due from Members account of entrance fees and dues	7,344.07	
Total Cash Receipts	$30,181.25	
Total Cash Disbursements	29,559.67	
		621.58

Property on hand according to Inventory May 1, 1903:

Office Furniture and Fittings	495.30	
Badges	154.50	
Transactions	2,957.50	
Congress Books	231.25	
Printing Material	125.00	
Library. Valuation for inventory purposes	9 436.75	
		$13,400.30

TOTAL NET ASSETS.

Cash	$2,006.75	
" Secretary Petty Cash	500.00	
U S Bonds, Market value	16,285.00	
Inventory (as above)	13,400.30	
		$32,192.05
Total Assets last year		30,192.05
Increase		$1,971.81

PROPERTY PURCHASED DURING THE YEAR.

(Reported as directed by the Constitution.)

Office Furniture	$207.00
Typewriter	100.00
Mailing Machine	19.60
Transactions Volumes	324.00
	$650.80

Respectfully submitted,

RALPH W. POPE,
Secretary.

TREASURER'S REPORT.

FROM APRIL 30, 1902, TO MAY 1, 1903.

GEORGE A. HAMILTON, TREASURER, in Account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from April 30, 1902	$ 1,385.17
Received from Secretary, May 1, 1902, to May 1, 1903	30,181.25
	$31,566.42

Cr.

Disbursements May 1, 1902, to April 30, 1903, on warrants No. 1556 to No. 1832	$29,559.67
Balance to New Account May 1, 1903	2,006.75
	$31,566.42

Respectfully submitted,

GEO. A. HAMILTON,
Treasurer.

The election of officers for the next year began with the sending out of nomination ballots in February last. The ballots which have been received recently have been turned over to a board of tellers, who have made out their report and it will be now presented. The officers elected now will take office on the fourth Friday of next September. Mr. F. W. Roller, chairman of the Committee of Tellers, has placed the report of the committee in the hands of the Secretary, who will now announce the result.

SECRETARY POPE:—The result of the ballot for officers as follows: For President, B. J. Arnold, 705 votes; 8 scattering; for Vice-Presidents, Calvin W. Rice, 687; W. S. Barstow, 677; R. D Mershon, 663; with others scattering; for Managers, Samuel Sheldon, 683; A. H. Armstrong, 672; W. C. L. Eglin, 644; G. F. Sever, 642, with a considerable number of scattering votes, the highest of which is 16 for A. E. Kennelly; for Treasurer, G. A. Hamilton, 713; for Secretary, R. W. Pope, 712; T. C. Martin, 1; total ballots, 764, of which 51 were defective.

PRESIDENT SCOTT:—The Chair declares that the following gentlemen have been elected the officers of the INSTITUTE for the ensuing year: President, B. J. Arnold; Vice-Presidents, C. W. Rice, W. S. Bartsow, R. D. Mershon; Managers, Samuel Sheldon, A. H. Armstrong, W. C. L. Eglin, G. F. Sever; Treasurer G. A. Hamilton: Secretary, R. W. Pope.

The Secretary suggests that the report of the Board of Directors presented in outline by the Chair and now before you in written form, should be acted upon. If there is any question to be asked or any action to be taken on the report, now is the time to take it.

UNION ENGINEERING BUILDING.

The first announcement before the INSTITUTE as a body of the progress which has been made toward a building for its uses can be made this evening. There has been for many years, since the foundation of the INSTITUTE, a conviction among its leading

members that it needed a building adequate for its present and future needs. There has been also for years a sentiment, sometimes fairly prominent, at other times seemingly almost forgotten, calling for a Union Engineering Building, in which the several large engineering societies could be housed together. We have been in a way acting on that principle ourselves, as we have been coming here to the house of the American Society of Mechanical Engineers, our brother engineers, and in common with them we appreciate the need of a larger house. These sentiments have been growing and have come to the attention from time to time of Mr. Carnegie. The matter of an engineering building has been discussed more or less informally in the past, so I think there has been in the mind of Mr. Carnegie a growing sentiment, a growing ideal in this direction, and he has probably been awaiting the time when the occasion would seem to be opportune, and when the conditions would be ripe for the materialization of this idea. Through the efforts of Mr. Martin, whom Mr. Carnegie designated as "irrepressible," we had the very great privilege and pleasure of entertaining Mr. Carnegie at our Library dinner on the 9th of last February. He seemed to enjoy himself that evening, entering into the spirit of things, and recognizing that he was among friends. He recalled the time when he was an electrician himself, in a cellar in Pittsburg. He saw how electricians had developed and grown, saw their influence, saw their possibilities, and it seems that he recognized that possibly now the time had come when something could be done. So he called before him two of the electricians who were at the dinner, and they met him the next day to have a friendly chat on the matter.

I need not tell the story. It has been sent to you in printed form in order that, as soon as the matter could properly be made public, you would be fully informed with regard to it. A meeting of three representatives from each society in conference committee has evolved a set of resolutions to be formally presented to the several bodies for action. These resolutions were brought before the Board of Directors of the INSTITUTE this afternoon, and with a few slight changes were passed as follows

RESOLUTIONS PASSED BY THE BOARD OF DIRECTORS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, MAY 19, 1903, WITH REGARD TO A UNION ENGINEERING BUILDING.

(1) *Resolved*, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS unite with the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and The Engineers' Club or any of them, for the purpose of accepting the sum of $1,000,000, as a gift from Mr. Andrew Carnegie, for the purpose of erecting suitable buildings for occupancy by the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF

ELECTRICAL ENGINEERS and The Engineers' Club, on the sites secured for that purpose on the north side of 39th Strect and south side of 40th Street, west of Fifth Avenue, in the City of New York, in the State of New York.

(2) *And Resolved Further*, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, has a very high appreciation of this generous gift of Mr. Andrew Carnegie, and this additional evidence of his recognition of the engineering profession and his deep interest in the welfare of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and The Engineers' Club.

(3) *And Resolved Further*, that a site on the north side of 39th Street shall be purchased and held by trustees, or otherwise as shall be determined by the joint committee hereinafter mentioned for the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, or by such of them as shall vote in favor of coming into this enterprise.

(4) *And Resolved Further*, that a joint committee shall be created to be composed of three members of each organization that shall unite in accepting said gift of $1,000,000 from Mr. Andrew Carnegie; and that the governing body of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS shall elect three members of this organization to represent it on and be members of such joint committee; and that the governing body of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS shall have the right and power to remove any member of such joint committee who shall be elected by it and to elect any member of this organization to fill any vacancy that shall occur in such joint committee by reason of the death, resignation, refusal to act or removal of any member who shall have been elected by the governing body of this organization as a member of such joint committee.

(5) *And Resolved Further*, that the character and internal arrangement of the building to be erected on the site on 39th Street shall be determined upon by the affirmative vote of at least two-thirds of all of such of the members of said joint committee as shall represent the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS or such of them as shall vote in favor of coming into this enterprise, on such joint committee; that the character and internal arrangement of the club building to be erected on the site on 40th Street, shall be determined upon by the affirmative vote of all of the three members of such joint committee who shall represent The Engineers' Club on such joint committee; and that the apportionment of funds between the two buildings shall be determined by an affirmative vote of two-thirds of the entire joint committee.

(6) *And Resolved Further*, that said joint committee shall, by the affirmative vote of at least two-thirds of all of the members thereto, select and employ an architect and such consulting engineers as may be necessary to prepare the plans and specifications for the building to be erected on the site on 39th Street and for the club building to be erected on the site on 40th Street; and shall also obtain proposals for the erection of both of such buildings; and shall have power to make and enter into such con-

tract or contracts as shall be approved and authorized by the affirmative vote of at least two-thirds of all of the members of said joint committee, for the erection of both of such buildings; and shall have charge of the erection of both of such buildings.

(7) *And Resolved Further*, that said joint committee shall continue in existence until all of the purpose set forth in these resolutions shall have been fully accomplished.

By direction of the Board, the committee in charge of affairs has submitted these resolutions to legal counsel and has the opinion of Paul D. Cravath, of Guthrie, Cravath & Henderson, as follows: " I return resolutions, which seem to me to be in proper form. They have the important merit of leaving the committee free to work out details of the proposed plan without being hampered by definite instructions."

The Board of Directors at its meeting this afternoon, in addition to adopting the resolutions, appointed as the permanent committee to represent the INSTITUTE, the present President of the INSTITUTE, the President-elect, Mr. Arnold, and Dr. Wheeler.

That is the history of the building plan up to date.

The attitude and views of some of the members of the INSTITUTE, among whom are many of our past Presidents, are before us in the form of a few letters which I am sure you will be pleased to hear. I will ask the Secretary to read some of these letters.

Secretary Pope read the following:

" ORANGE, N. J., May 18, 1903.

CHARLES F. SCOTT,
President AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City.

DEAR MR. SCOTT:—I am delighted to note the sequel of the INSTITUTE Library Dinner which I had the pleasure of attending last February, and am heartily glad to be able to congratulate you on the generous gift of Mr. Carnegie of one million dollars to the INSTITUTE and its sister societies. I have the greater pleasure, in this benefaction to the society, because it comes from one of ourselves, who began at the key and has shown himself so worthy of the great wealth that has come to him since he was a humble telegrapher.

I am convinced that all the societies concerned will feel it their duty to unite in the disposing of this gift so as to render it of the utmost value and profit to the professions they represent and to the arts and sciences in general.

Faithfully yours,

THOMAS A. EDISON."

" CAMBRIDGE, MASS., May 14, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City.

GENTLEMEN:—It gives me great pleasure to learn that it is proposed, with the generous aid of a world-widely known man, whose success has been achieved in connection with engineering development, to erect a useful and enduring structure of steel and stone that shall attest and perpetuate the essential unity of all engineers and engineering in subjugating nature to the rising needs of humanity.

It seems to me that no more valuable endowment could be made for engineering than that which will harmonize and unite the various engineering societies, bringing these bodies into one building, and building them into one body. It would bring into closer coöperation the branches of that guild whose past industry has made possible the greater coöperation and the grandest civilization that the world has already won.

I sincerely hope that this proposition may duly assume outline on paper and speedy realization in stone. I regard it not merely as a lasting benefit to engineers, but also through their labors, and the work that they will carry on in the Union Engineering Building, as a distinct gain to all the nations of the world.

With every good wish for the success of this project, I remain, gentlemen,

Yours very sincerely,

A. E. KENNELLY."

"PHILADELPHIA, PA., May 18, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,
New York City.

DEAR SIRS:—Just two years ago a committee of this INSTITUTE held a conference with Mr. Andrew Carnegie concerning the Clark library, the result of which was that Mr. Carnegie, with his world-renowned generosity, presented the INSTITUTE with a sum of money equal to the original cost of the library, to be used for its maintenance. The subject of a home for the INSTITUTE and its library was also approached at that time, and the parting words of Mr. Carnegie to our committee were to the effect that as soon as we felt able to maintain a home we should call to see him again.

From his recent magnificent offer, Mr. Carnegie seems to consider that we are now able to maintain a home, even a much larger and more magnificent one than was contemplated two years ago. That he did not over estimate our abilities to do this, is the belief of those of our members who have been most active in this effort to provide the INSTITUTE with a much-needed home. It therefore becomes the duty of every loyal member who has the interest of the INSTITUTE at heart to assist our able and energetic committee and President in every possible way, in order that the grand project which they have planned may be successfully carried out.

Those of our members whose fortunes have been made in the electrical industry and profession now have an opportunity to follow the generous example set to Mr. Carnegie by recognizing in a substantial way the institution which has been such a potent factor in the marvelous development of an industry which has brought fortunes to many.

This INSTITUTE is now recognized to be of national importance, and during the past few years its reputation and standing is beginning to be recognized abroad. It has no rival in its branch of engineering in this country. National questions are referred to it and its opinion on international matters is respected.

Although the youngest of the national engineering societies, it has been the most active in the efforts to realize that long-cherished dream of so many engineers, a Union Engineering Building in the Metropolis of our country. We should therefore not be the last to assure Mr. Carnegie that he has not overestimated our abilities to maintain the magnificent home, which he has so generously offered us.

Very respectfully yours,

CARL HERING,
Past-President."

"NEW YORK, May 12, 1903.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
New York City

GENTLEMEN:—I certainly think that it will be of the greatest advantage to the work of the INSTITUTE if the plan respecting a Union Engineering Building can be carried out. The INSTITUTE must certainly have a place for housing its library and nothing need be said about the advantages of

bringing together the libraries of the different engineering societies. The advantages of such a union are self-evident. While my duties at the Cooper Union for the last eight years have so occupied my evenings that I have not been able to attend many of the meetings of the INSTITUTE, I have felt the keenest interest in its work, and I know that the papers that have been read and the discussions that have followed upon various subjects have helped very greatly to advance the interests of the electrical art, and if a building can be secured where the INSTITUTE can have permanent quarters in connection with the other Engineering Societies I am sure it will increase greatly the efficiency, not only of its work, but of that of the other societies also.

I hope nothing will prevent a favorable action upon this matter.

Yours very truly,

WM. A. ANTHONY."

PRESIDENT SCOTT:—There is one phase of the building matter which I did not refer to in my remarks a few moments ago. When on the first afternoon the general subject was under discussion with Mr. Carnegie and we were talking over the whole proposition, and he was concerned where we could get the land and what it would cost, we presented to him an outline of the present status of the various bodies; their financial standing, their membership, income, what they were now paying in rents, etc., and he at once said, "Why, you are able to carry yourselves; if you can provide the land for the building and take care of it, I will give the building." He seemed to think that providing the building was the easy part, and the other was the hard part. In the aggregate the various organizations concerned are able to carry the land very well. We Electrical Engineers are most of us young men starting out in life, not like the members of the older societies, who have made their fortunes. Consequently, our Institution is not in the financial position which the others are, and when it has now come time to go in and take our share in this matter we find ourselves in a different position from the other societies.

The estimates of the committee as reported to the Board, and which in general receive the sanction of the Board, though the Board did not go into the matter in detail, shows in a general way that the INSTITUTE should have a fund of about $200,000 to put it in good condition to assume its fair part in this new enterprise. There are various ways in which this money could be secured, in fact it is quite possible that in four or five years from now the INSTITUTE will be as able to pay the interest on bonds to provide for the land as it has been in the past to pay rentals. But that is not what we would like to do. The INSTITUTE is growing and developing; its committees go to the limit in expending the appropriations; nearly every committee could enlarge its work. Our new committee on local organizations, which is developing the work of the INSTITUTE throughout the country so finely, calls for an expenditure of more funds for the printing of Transactions and the like, and for the local running expenses of the several organizations. That is but one example. Every way we turn our work is costing more and more as we

expand, and make the work more efficient, so that what we ought to have is such a provision for the land as well as the building which will enable the current income of the INSTITUTE to be used for its current expenses and its technical work.

We have made this suggestion, which I have just indicated to you, to a few members and we are pleased to-night to be able to announce a few subscriptions as a beginning to what we hope will continue for some time in the future to be a growing fund.

We have the following letter from a past-President of the INSTITUTE:

"NEW YORK, MAY 11, 1903.

T. C. MARTIN, ESQ.,
Committee on Union Engineering Building,
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

MY DEAR MR. MARTIN:—I wish to add a word of congratulation on the possibilities of development assured the INSTITUTE by the magnificent offering of Mr. Carnegie for the erection of a Union Engineering Building in connection with the Engineers Club.

Not many years have passed since the inauguration of our society, but already the self-sacrificing labors and constant efforts of its officers, among whom none have been more faithful to its interests than yourself, coupled with the unparalleled growth in the various branches of the electrical industry have brought the INSTITUTE to a position where it must necessarily be more commanding in its engineering influence.

With its growth has come the greater need of the highest professional equipment on the part of those composing its membership and dominating its councils.

The work of the universities and technical schools, and the great responsibilities now involved in electrical undertakings, requires the highest professional standard. The successful engineer in electrical work must no longer be simply an electrical engineer, but coupled with his specific knowledge must be mechanical and civil engineering attainments of high order. On account of the diversity of work few can be expert at all branches, but they must at least have sufficient knowledge to fairly guide them in enterprises requiring the highest skill in every branch.

These facts make it all the more essential that instead of the engineering societies being individualized they should be brought in closer touch so that opportunities may exist for each to become better acquainted with the other, and to gather by intuition, as well as by specific instruction, completer knowledge of engineering practices, and especially to have the advantage that technical libraries housed and technical papers given in a common building may grant.

While it is perhaps natural that such a building shall have as its principal attraction the technical libraries of the different societies, which should, under suitable restrictions, be accessible to all members, it would seem proper that it might also have in its equipment as a source of inspiration and instruction, a collection of models of the original apparatus illustrative of important departures in engineering practices.

As a member and a past-President of the INSTITUTE, I am in hearty accord with the general plan which has been proposed for a building to be occupied as a common home, and I will gladly bear some portion of the burden which will fall upon our particular INSTITUTE, to which end I take pleasure in authorizing you to say that in the event of the proposed plan maturing I will subscribe $2,000 for such fund and under such conditions as may be established in accordance with the general circular of May 9.

Sincerely yours,

FRANK J. SPRAGUE."

PRESIDENT SCOTT:—We have a letter from Prof. Elihu Thomson, which the Secretary will read. In addition to this letter, the Secretary also has a letter from Prof. Thomson making a contribution of $5,000 to the building fund.

"SWAMPSCOTT, MASS., May 16, 1903.

MESSRS. CHAS. F. SCOTT and T. C. MARTIN,

GENTLEMEN:—Just fourteen years ago I had the honor and duty of addressing, as the representative and President of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, a unique gathering in the Guildhall, London. There were present the leading engineers of Great Britain and their guests, the visiting American Engineering societies, altogether about six hundred. Among these the electrical engineers formed but a small percentage. Our art was young and our INSTITUTE very young. Our art is still young and so is our INSTITUTE compared with the other engineering bodies. But its record of creditable work is not excelled. There is in it plenty to awaken our members to the importance of assisting in all possible ways in laying the new foundation upon which the future of the INSTITUTE will rest.

It is not conceivable that any member can fail to be deeply interested in the new possibilities and opportunities which arise out of the munificent offer of Mr. Carnegie. By his most generous gift he has shown his own deep interest in the work and in the future coöperation of our chief engineering bodies. The membership of those bodies now have the duty of seeing to it that the gift is largely used and in a way to redound forever to the credit of American engineers.

There is no need to dwell upon the importance of the work of our INSTITUTE in the past. Who can doubt that with the enormously enlarged opportunities now to be afforded that there will be a great extension of its usefulness in the future.

Respectfully yours,

ELIHU THOMSON."

PRESIDENT SCOTT:—We will now pass from the list of our past-Presidents—every letter which has been read, except the first, from Mr. Edison, has been from a past-President—to the roll of our members.

Secretary Pope read the following letter:

"NEW YORK, May 13, 1903.

MR. CHARLES F. SCOTT,
Pittsburg, Pa.

MY DEAR MR. SCOTT:—The proposed Union Engineering Building impresses me as being a magnificent project and all of the engineering fraternities are certainly indebted to Mr. Carnegie for his liberal offer. It will give me great pleasure indeed to contribute toward the portion of the fund for land which must be raised by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Toward this I shall be very glad to send you at any time the money is required a check for $1,000. In addition to this, I shall be very pleased at any time to confer with either Mr. Rice, Mr. Martin or yourself, regarding the matter which has been referred to this committee, and it will be a pleasure to me to render any assistance possible.

Wishing you great success in your endeavors, I remain,

Very sincerely yours.

J. G. WHITE"

PRESIDENT SCOTT:—I have made a memorandum on the bottom of this letter from Mr. White as follows: May 16, 1903. Mr. White stated to me that if the whole of the amount necessary be raised by the INSTITUTE by subscription he would increase his contribution by $1,500, making a total of $2,500.

In addition to the individual contributions which have been mentioned, it is expected that a number of the electrical companies will take part in this enterprise. We have been consulting with gentlemen connected with a few of them. We have re-

ceived encouraging words in several quarters. Arrangements of that kind naturally take a little time for consummation, so that to-night only one can be announced. Mr. Osborne, the Fourth Vice-President of the Westinghouse Electric&Manufacturing Company, authorizes me to state that, with the expectation that other companies will join in the enterprise, the Westinghouse Company will contribute $5,000 to the building fund. We have here in the very beginning, a number of substantial contributions toward this end. We want to awaken and maintain a live interest in this subject on the part of all who should be interested in it. It is not a matter of begging for assistance, but it is presenting the matter on its merits and expecting recognition of those merits. I think we are justified in taking a few minutes now for an expression of opinion on this building scheme by the gentlemen who are present here this evening. As we have one of our donors here this evening, I am going to ask Mr. White to say a word, and to stand up a moment so that we can get a sight of him.

MR. J. G. WHITE:—I have not much to add to the remarks contained in my letter which was read a few moments ago. I should particularly like to see the entire amount which must be provided by the INSTITUTE, raised by contributions of members and friends, and none of it raised by mortgage on the land which the INSTITUTE must acquire. I understand that it has been suggested by Mr. Carnegie himself that part of the necessary money may be secured by such mortgage. It seems to me that it is possible for the INSTITUTE to secure sufficient funds to pay for its portion of the necessary land without resorting to such mortgage loan. With contributions such as just announced from the Westinghouse Company, Prof. Thompson and others, and with the many contributions which will undoubtedly be available, it ought to be possible for the INSTITUTE to raise all the funds needed.

If this cannot be done immediately, we must resort to a loan, which should have a sinking fund provision, by which the amounts borrowed will gradually be repaid leaving the land of the INSTITUTE free and clear of indebtedness.

PRESIDENT SCOTT:—We would like to hear from Mr. Martin, one of our past-Presidents, who began work as President a long while ago and never stopped.

MR. MARTIN:—I am obliged to you for calling upon me, Mr. President, but I think there has been enough said about me. I want to do a little more work, that is all.

PRESIDENT SCOTT:—Mr. B. J. Arnold, of Chicago, has just been ushered into this work this afternoon, being put on the committee to represent the INSTITUTE, and I can assure him there is work ahead for him.

MR. ARNOLD:—I think the best speech I can make to-night will be to remain absolutely silent for I can show better by my actions during my term of office than my words would express to-night what I shall do toward making the venture now considered a complete success. I will do all I can to that end.

MR. MARTIN:—I would suggest, Mr. President, that we voice our gratitude to Mr. Carnegie; that we send him a cable message of gratitude.

PRESIDENT SCOTT:—The Board of Directors this afternoon authorized the sending of a cable message of thanks to Mr. Carnegie and asked that Mr. Mullin confer with Mr. Martin to draft a suitable cablegram. As Mr. Mullin does not appear to be present, it still looks as if all the work will fall on Mr. Martin.

There is one man who ought to be here to-night as he is one of a number who have been promoters of the building idea, and to whom a great deal of credit is due. He has been chairman of our building committee which has been planning and hoping for a long time; but all at once the ideal has culminated in a great good fortune which is now ours. The man to whom we are so much indebted is Mr. Calvin W. Rice, who with the President, was summoned by Mr. Carnegie on the day after our annual dinner last February.

The Board of Directors asks that the INSTITUTE pass the following resolution: The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS at its annual meeting endorses the action of its Board of Directors in the adoption of resolutions looking to the acceptance by the INSTITUTE of the generous gift of Mr. Andrew Carnegie in his letter of February 14, 1903, giving one million dollars for the purpose of a Union building, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the Engineers Club.

Mr. J. G. White moved the adoption of the resolution, and the motion was unanimously carried.

MR. MARTIN:—Mr. President, the cablegram which I have drafted to be sent to Mr. Carnegie is as follows:

ANDREW CARNEGIE,
SKIBO CASTLE, SCOTLAND.

The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, in annual meeting assembled, accepts with gratitude and sends you hearty thanks for its share of your generous gift of the Union Engineering Building, and pledges its best efforts to render your great benefaction useful in the promotion of electrical and other engineering arts and sciences.

Mr. Dunn moved that the cablegram be forwarded. Motion carried.

SECRETARY POPE:—The committee on proxies reports a total of 270 proxies. Those holding the principal proxies are R. W. Pope, 136; B. J. Arnold, 31; C. F. Scott, 15; R. T. Lozier, 12; blanks, 21; rest scattering. A quorum of 159 is necessary. 186 proxies are held by gentlemen who are present, so that there is a quorum present.

PRESIDENT SCOTT:—If the proxies are not called for, the vote on the resolution just passed will stand.

SECRETARY POPE:—In regard to the annual report submitted by the Board of Directors, I would say the contribution of Mr. C. O. Mailloux, of about $1,100 to the library, which was reported about a month ago, is still in the hands of the secretary, owing to a question in regard to its proper investment. It does not appear in the report. There is also about the same amount which has been contributed for books by another gentleman, which is not yet included in the report. The valuation of the library at $9,436.75 is simply an inventory value at $1 per volume. The Library Committee is now making a report which will give the appraised value more in accordance with the actual value of the books.

A paper read at the 177th Meeting of the American Institute of Electrical Engineers, New York, May 19, 1903.

THE EXPERIMENTAL BASIS FOR THE THEORY OF THE REGULATION OF ALTERNATORS.

BY B. A. BEHREND.‡

The presentation of this paper has been undertaken with a view to supplying the Committee on Standardization with data to enable them to draw up rules for the determination of voltage regulation, as Section 71 of the INSTITUTE rules is, by no means, in accordance with fact and observation.

Many papers have been published by various authors on the theory of voltage regulation in alternating current machines, but their writers have been sadly in the dark as to the actual facts which a complete theory has to explain. This state of affairs is perfectly natural, as experiments on large modern machines are extremely difficult and costly, and few men have either the patience or the opportunity to carry out series of measurements which can be used as a foundation upon which the theory of regulation can be built. A theory which is not supported by facts is worse than none, and yet without theory it is impossible to design rationally and economically any kind of apparatus. Designers of alternating current machinery who ten years ago began to develop for themselves the necessary theoretical basis for their designs, will, no doubt, appreciate the difficulties which they had in obtaining a clear view of the many conditions to be taken into account in designing alternating current generators.

‡ Papers by the Author on "Regulation in Alternators."

Electrotechnische Zeitschrift, Berlin, 1897, pages 715 and 771. Letters on "Armature Reaction and Potential Drop in Alternators."

1899, No. 48, "On Potential Drop in Alternating Current Generators."

L'Eclairage Electrique, Paris, 1900, p. 140, "Sur le Calcul des Alternateurs."

Electrical World and Engineer, New York, 1900, January 20, 27 and February 3. "The Factors which Determine the Design of Single-phase and Multiphase Alternators."

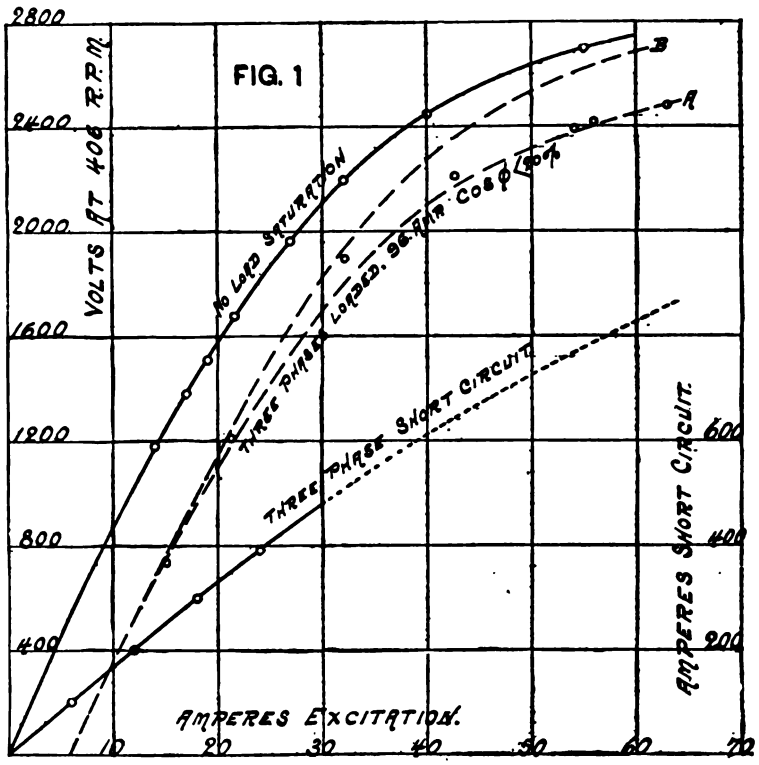
and synchronous motors. And no doubt they will remember that the greatest difficulty which they encountered was the question of how to determine the inductive drop in the armature.

The subject matter of this paper is to supply an array of experimental data obtained on the most modern designs of alternating current generators. A somewhat empirical theory is given in this paper, which satisfactorily explains quantitatively and qualitatively the observed results; but no attempt is made in this theory to take into consideration the many varying factors that would naturally have to be introduced into a complete theory of the phenomena of regulation.

The presentation of this paper has been undertaken, partly, with a view to supplying the Committee on Standardization with data to enable them to draw up correct rules for the determination of voltage regulation, as Section 71 of the INSTITUTE rules is, by no means, in accordance with fact and observation. The matter being of extreme importance, the duty devolves upon the designing engineers, who have accumulated experimental evidence, to publish this evidence so as to enable consulting engineers to draw specifications intelligently without asking for phvsical impossibilities.

The term " regulation " is vague and has been used very loosely. We understand by the regulation of an alternating current generator, the increase in per cent. of the terminal voltage consequent upon throwing off the load, the speed and exciting current remaining the same. Our problem consists in determining the terminal voltage for any current and power factor for various ampere turns excitation. In practice, it is difficult to make tests under load, especially on very large units. Therefore, it is necessary to have a method which enables us to determine the terminal voltage for any current and power factor from tests which can easily be performed. The first attempt to do this was made by Dr. Behn-Eschenburg of Oerlikon in 1892. It is a curious coincidence that the experiments which Dr. Behn began and which I continued extensively at the Oerlikon Works were made on types of alternators which bore out and corroborated Dr. Behn's theory, although this theory does not represent the actual conditions on modern machines. The first experiments were made on machines of the Lauffen type, and later experiments were made on machines of the inductor type, both types of machines being carefully designed. Dr. Behn suggested that if the open circuit saturation curve of the generator was

known, as well as the current which the machine generated in short circuit, we could obtain the apparent impedance of the armature by dividing, for a given excitation, the volts on open circuit by the amperes in short circuit for the same excitation. This theory, superficially considered, appears very plausible; but it is evident that it throws together, without explanation or justification, the armature reaction and the self-inductive effects produced by the local fields in the armature.



Regulation Curves on 500 k.w. 3-Phase Induction Generator.

It appears plain that, for all we know, the local fields might be independent of the saturation of the machine, while the effect of armature reaction would, of course, be dependent upon the degree of saturation. The experimental investigation was encumbered by the fact that the power factor plays such an important part in the magnitude of the inductive drop. In order to simplify the conditions, we have only to consider that the drop in an alternator is a maximum if the power factor is a minimum.

It can also be readily shown that if the power factor is diminished below 20 per cent., the drop will practically remain unchanged, the error being extremely small in assuming that a power factor of 20 per cent. or less is equivalent to a power factor zero, as regards inductive drop.

The alternating current generators built during the past ten years have had to operate mainly upon induction motor loads. At least this is true in regard to the generators built in the early nineties in Europe, as induction motors were then used there on a large scale. It seemed to me it was logical to demand that a generator should be capable of standing an induction motor load equal to its rated kilovolt amperes. Therefore, all my machines were designed so that they could give their full rated output in kilovolt amperes on a load of any power factor. These machines were tested by using, as a load, induction motors running idle, so as to be sure that the power factor would be below 20 per cent.

TABLE I.

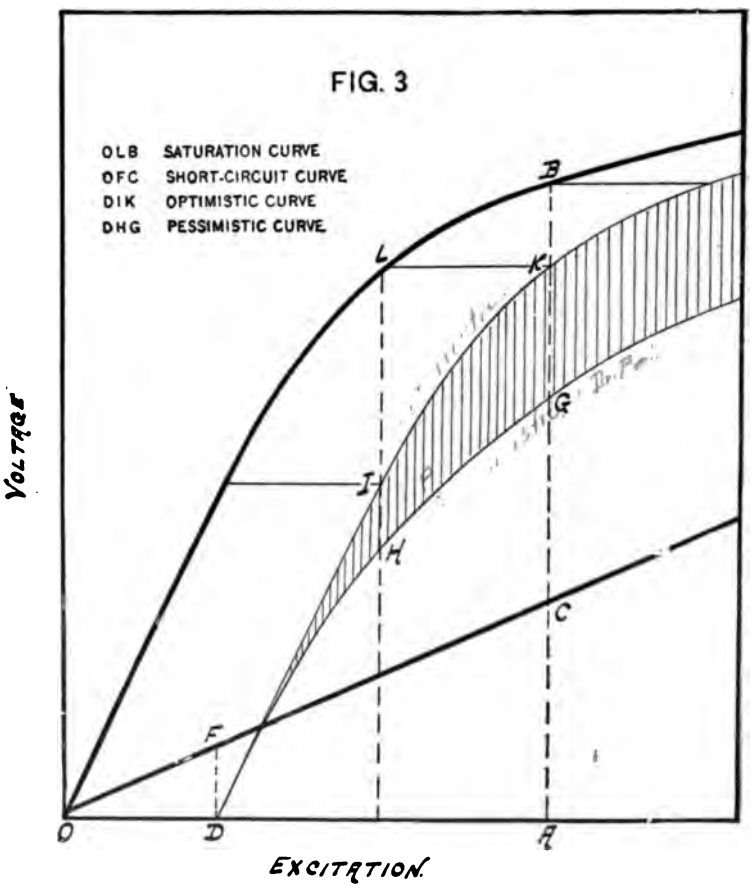
Amperes Excitation	Actual Terminal Voltage	Calculated Terminal Voltage.		Regulation per cent.		
		A	B	Actual	A	B
10	360	365	356	143.	140	145
20	1110	1115	1140	41.5	41	37.7
30	1700	1688	1840	24.1	25	14.7
40	2100	2073	2290	16.6	18.7	7.4
50	2330	2300	2540	13.7	15.2	4.35
60	2460	2431	2700	12.3	13.1	1.85

In order to obtain very large currents, I used synchronous motors running without, or with very slight, excitation. The simplification thus obtained in interpreting tests and theory is worthy of notice.

Fig. 1 shows the saturation curves at no load and at 96 amperes load, $\cos \varphi < .2$, as well as the short circuit curve, of a large inductor generator built six years ago at the Oerlikon Works. The magnetic circuit of this machine is represented in Fig. 2.

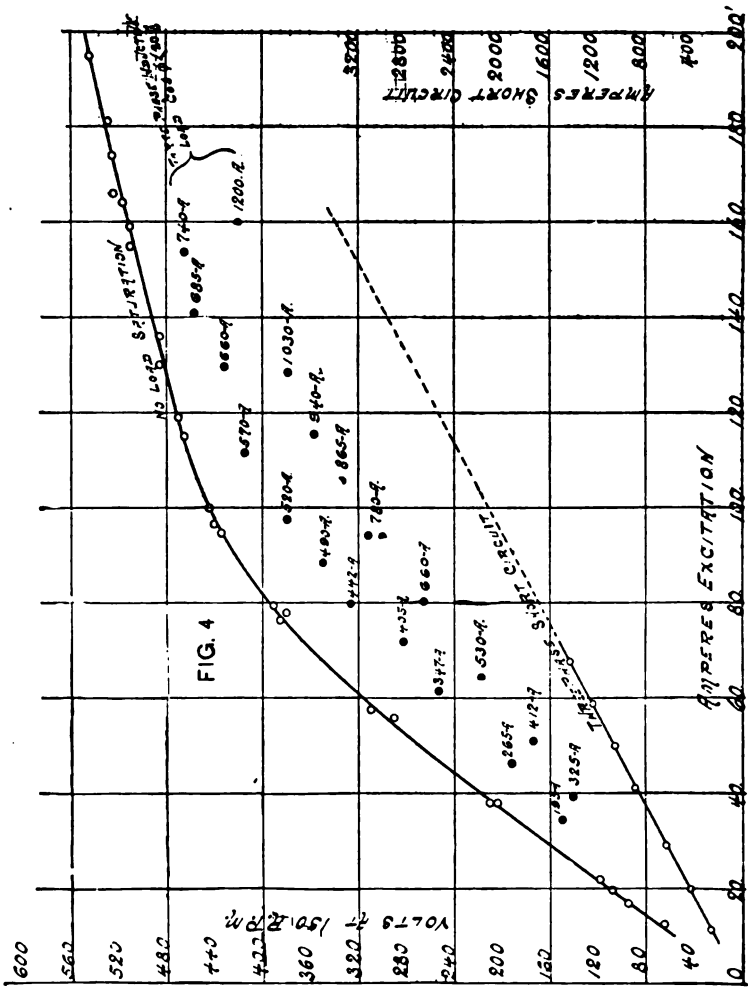
Applying Dr. Behn's method to these curves and referring to Fig. 3, where O B represents the saturation curve, and O C the short circuit curve, we find the apparent reactance, neglecting ohmic resistance, by dividing A B by A C. If we wish to determine the inductive drop for a current represented by D F equal to one-third A C, we reason, according to Dr. Behn, that as it takes an e.m.f. equal to A B to drive a current equal to A C through the short-circuited armature, it will take an e.m.f. equal

to D F ÷ A C, equal to one-third A B, to drive a current D F through the armature. We thus obtain a point G, B G being equal to one-third A B.. Applying the same reasoning to different excitations, we obtain a curve D H G, which represents the terminal voltage at different excitations for a constant current F D at a power factor zero. Applying this method to Fig. 1, we obtain the results compiled in Table I.



In applying the rule of paragraph 71 of the Committee on Standardization, we have only to remember that, referring to Fig. 3, it takes an excitation corresponding to O D to produce a current D F in the short-circuited armature. Therefore, following the INSTITUTE rule given in paragraph 71, in order to get the load saturation for a current D F on a power factor zero, we have

to deduct the ampere turns O D from the ampere turns on open circuit. The result is curve D I K, the distances between this curve and the curve O L B measured along the abscissa being the same.



Regulation Curves on 500 k.w 3-Phase Generator.

In Table I. there are placed side by side, the actual regulation obtained by experiment and the regulations as calculated from Dr. Behn's method, and as determined by the rule of paragraph 71 The results obtained by the former method are given in column "A"; the results obtained by the latter method are repre-

sented in column " B." It is evident that method " A " gives results which are very nearly accurate, while the error resulting from the use of method " B " is greater than 700 per cent. at high saturations. For the straight part of our saturation curve, the above methods give the same results.

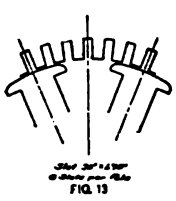


FIG. 13

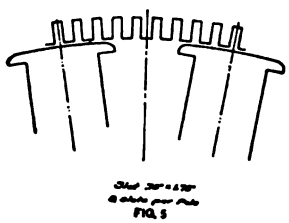


FIG. 5

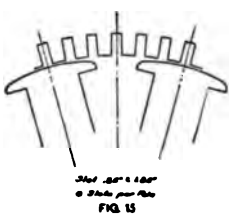


FIG. 15

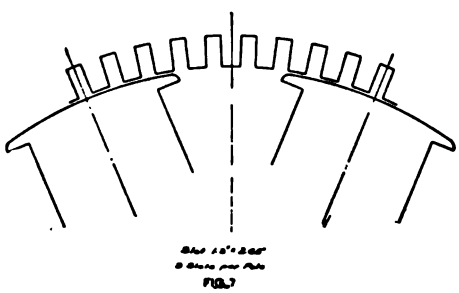


FIG. 7

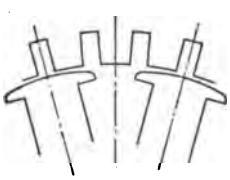


FIG. 12

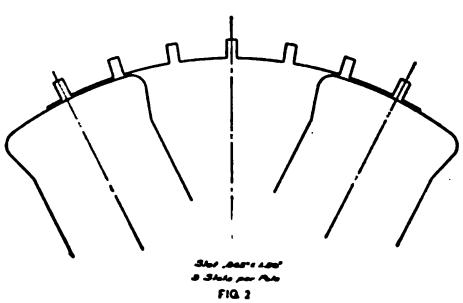


FIG. 2

For the saturated part, method " B " yields in this case a regulation which is several hundred per cent. smaller than the actual regulation, while method " A " yields a regulation which is a few per cent. larger than the actual regulation. These tests were made on a large inductor generator with small air gap and large

pole pitch, which are the best possible conditions for good regulation. Fig. 2 shows the number and size of slots and other details.

We will now apply the two methods " A " and " B " to a 500 k.w., 3-phase generator designed with all the finesses that can be employed to obtain good regulation with greatest economy of material. The machine on which the tests were made was designed for 400 volts, 3-phase, 25 cycles and was run at 150 r.p.m. The load consisted of rotary converters running without excitation.

Fig. 4 shows the observed data in the form of a curve, while Fig. 5 shows the magnetic circuit. Leaving it to the reader to check the many observed points for himself, we will refer to a few points to illustrate the argument. For instance, take the point observed at 160 amperes excitation. Here the e.m.f. on open circuit is 512 volts, the terminal voltage at 1200 amperes load, $\cos\varphi < .2$, is 420 volts. The short circuit current at this excitation is 3400 amperes. According to method " A," we obtain an inductive drop equal to $1200 \div 3400 \times 512 = 181$ volts; by method " B " we obtain 102 amperes excitation as resultant excitation, which corresponds to 448 volts terminal pressure. Hence the following table:

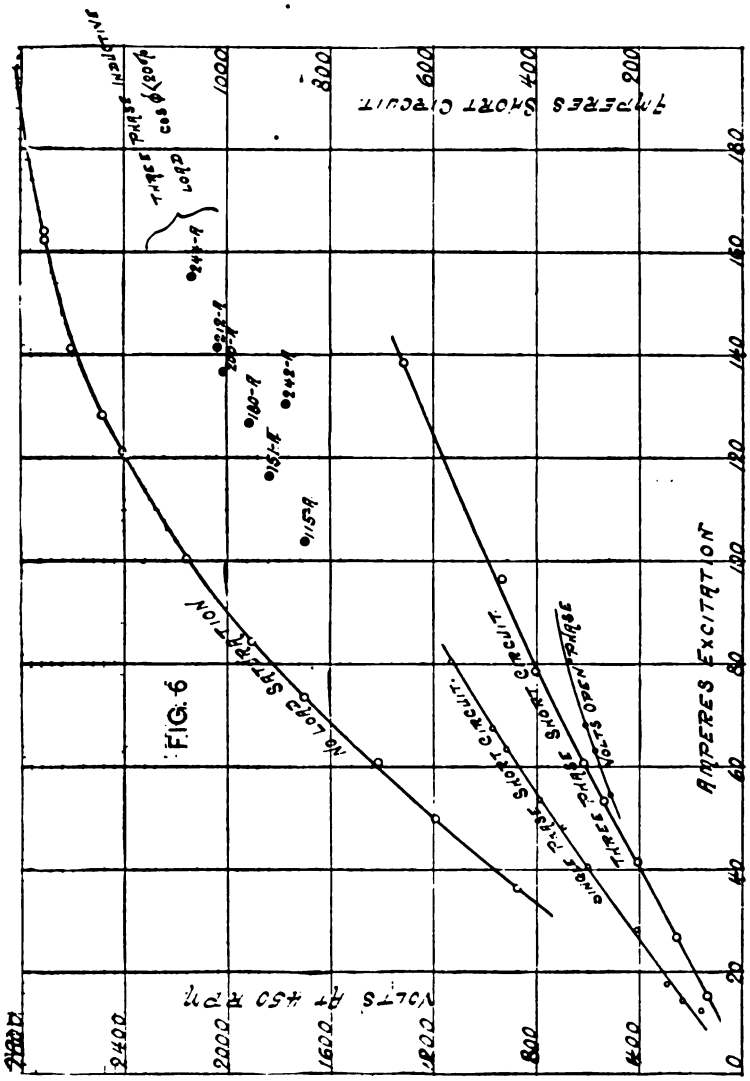
TABLE II

REGULATION.

Actual.	A	B
22%	54.5%	14.3%

The state of affairs in this case has become reversed, and method " A," which gave approximately accurate results on the inductor generator, gives results which are over 200 per cent. too large on a well designed revolving field generator, while method " B " yields a regulation which is about 50 per cent. too small. To adduce some further evidence to show the inherent errors of the two methods, there are shown in Fig. 6, the experimental curves taken on a 1600 h.p. synchrouous motor operating on a 3-phase system at 30 cycles and 450 r.p.m. The magnetic circuit of the motor is represented in Fig. 7, and a picture of the machine is given in Fig. 8. Method " A " gives, at 155 amperes excitation, 244 amperes load, a terminal voltage of 2130. Method " B " yields a terminal voltage of 2240 volts. The actually

observed terminal pressure was 2130 volts. Now, it is clear that neither method " A " nor method " B " yields accurate results in this case, but method " B " approaches somewhat more closely



Regulation Curves on 1600 h.-p. 3-Phase Synchronous Motor.

to actual facts than method " A " does. These curves were taken by running the synchronous motor as a generator. The tests were made by taking two machines, one running as generator, the other as motor

Returning once more to Fig. 3: Some five-years ago the writer named the method "A," which yielded the regulation curve D H G, the "pessimistic method," while he called the curve D I K obtained by applying method "B," or the INSTITUTE method, the "optimistic method." These names have since been widely used in European electrical journals. There is some justification for using these terms as, from the standpoint of the designer, the application of method "A," which we will in the future call the "e.m.f. method," yields terminal pressures which are much smaller than the ones he will actually obtain, while method "B,"

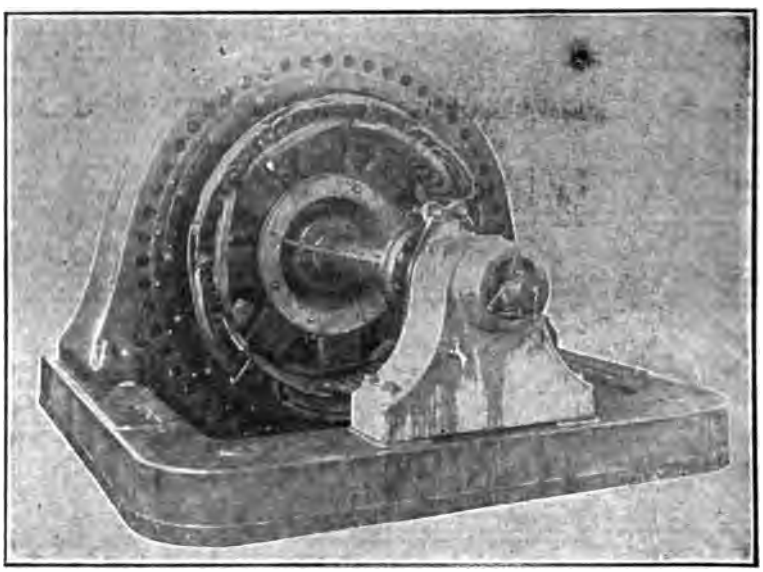


FIG. 8.

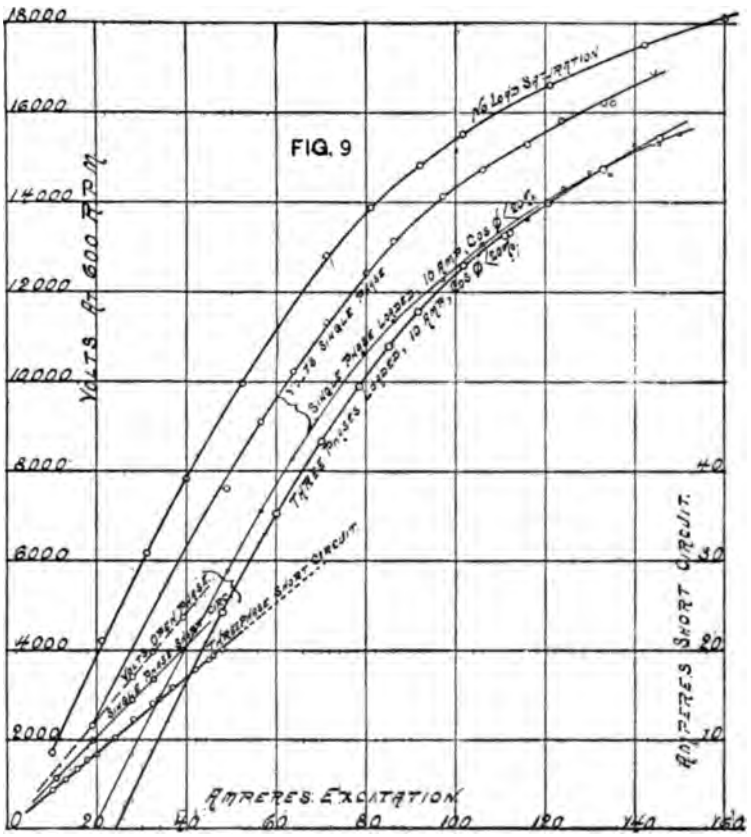
which we will call the "ampere turn method," yields values for the terminal pressure which are considerably greater than the ones he will actually obtain. A machine designed according to the ampere turn method will give less volts than required, while the machine designed by the e.m.f. method will give more volts than required.

Again referring to Fig. 3, it is clear from the evidence so far adduced that the curve for the actual terminal voltage lies between the two curves D I K and D H G; that is, between the optimistic and pessimistic curves. But, further to corroborate this statement, there are shown regulation curves in Fig. 9, Fig.

10 and Fig. 11, Figs. 10 and 11 being reproductions of the 3-phase and single-phase load curves with the optimistic and pessimistic curves plotted in the diagrams. Fig. 9 shows also the e.m.f. between the open phase and either of the two terminals of the loaded phase. This curve will be referred to later.

The magnetic circuit of this machine is shown in Fig. 12.

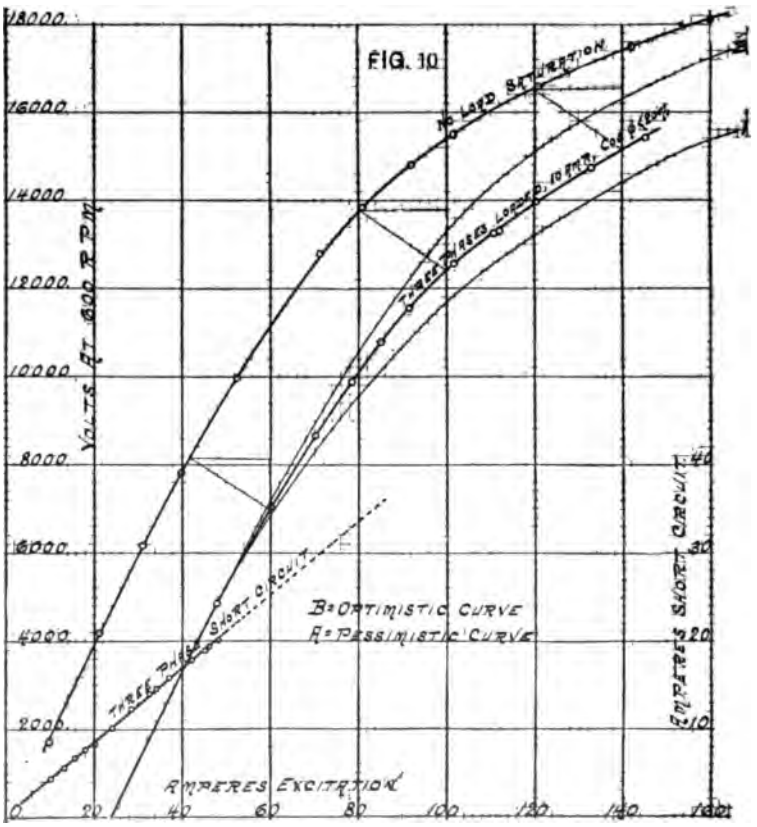
The figure shows the shape of the poles and the shape and size of the slots. The curves in Figs. 9, 10, and 11 belong to a gener-



Regulation Curves on 3-Phase Generator.

ator the normal rating of which is 200 k.w. at 13,000 volts and 60 cycles. The load saturation was taken by running two of these machines together, one operating as generator, the other as synchronous motor. The power factor varied between 8 and 15 per cent. Fig. 10 represents a 3-phase load, while Fig. 11 represents a single-phase load. These curves are well fitted to bear out the essential parts of the theory of the regulation of alter-

nators, as they indicate clearly that the armature ampere turns which are opposed to the field ampere turns are large in the 3-phase machine and small in the single-phase machine; while the e.m.f. produced by local armature fields is small in the 3-phase machine and large in the single-phase machine. These conditions result in the load saturation curve of the single-phase machine lying very close to the pessimistic curve, while the load saturation of the 3-phase machine lies about half way between the



optimistic and pessimistic curves. These diagrams show the armature reaction separated from the self-inductive effect of the local armature fields. The side of the triangle which is parallel to the abscissa represents the armature reaction, and the side parallel to the ordinate represents the self-inductive effect of the local fields. From the curves in Figs. 10 and 11 it is seen that by resolving the total inductive drop into such components

results are obtained which are very closely in agreement with actual observation. However, there remains the difficulty of separating these two components. We add Fig. 12 to our experimental data, representing the regulation curves of a 100 k.w., 900 r.p.m., 60 cycle, 3-phase generator, the magnetic circuit of which is represented in Fig. 13. The curves contain a no load saturation; a saturation curve for 30 amperes 3-phase load of low power factor; a saturation curve for 30 amperes, single-phase load, low power factor; a curve giving the voltage between either one of the two phases operating single-phase, and finally the 3-phase and single-phase short circuit curves. It need hardly be remarked that the single-phase curves were obtained by operating two phases of the Y connected machine in series. The curves in Fig. 12 are condensed in Table III.

TABLE III

100 *K.W.*, 3-*Phase Generator.*

Amperes Excitation	E. M. F.	Terminal Voltage.	Terminal Voltage Calculated by Institute Rule.	Regulation per cent	
				Observed.	Calculated by Institute Rule
16	2080	1050	1050	98	98
20	2330	1530	1600	52.5	45.6
24	2500	1850	1980	35.1	26.2
28	2040	2060	2260	28.2	16.8
32	2755	2250	2460	22.5	12

A glance at this table shows that as soon as the saturation of the machine begins, the ampere-turn method, which is embodied in the INSTITUTE rule, gives results that fall very far from the mark. For instance, we observed at 28 amperes excitation a regulation of 28.2 per cent., while we calculated only 16.8 per cent. At 32 amperes excitation the case is even more striking, as we observed 22½ per cent. regulation against 12 per cent. as calculated.

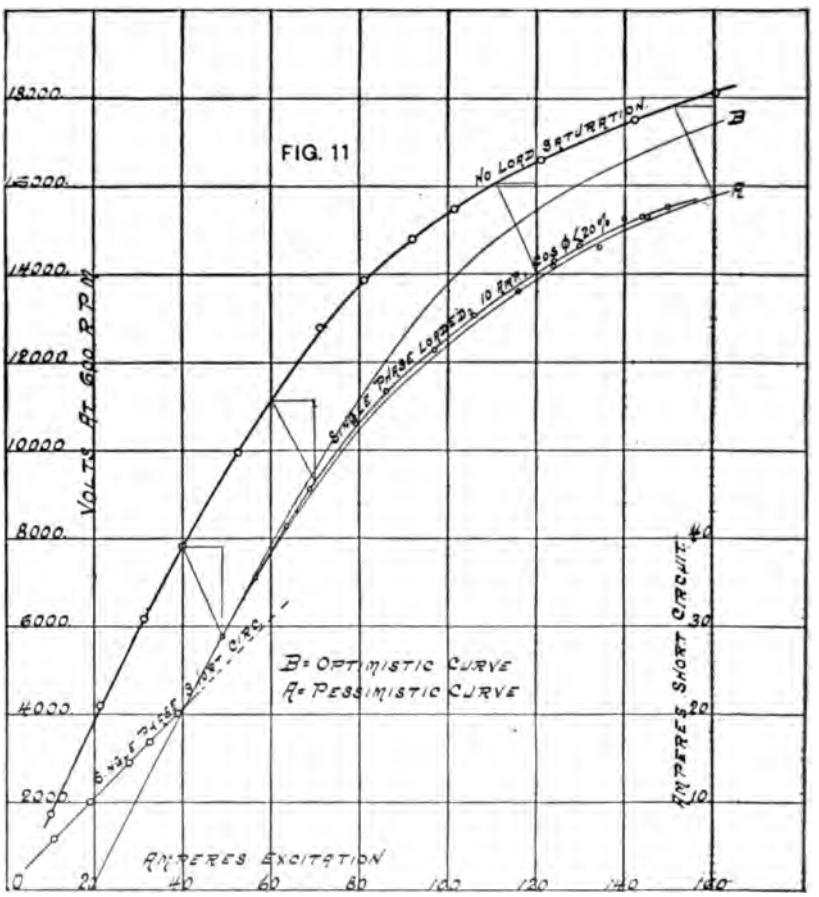
In Fig. 14 are given the regulation curves of a 350 k.w., 2-phase generator operating at 60 cycles and 600 r.p.m. This figure also contains the curves for single-phase load. The magnetic circuit

TABLE IV

350 *K. W.*, 2-*Phase Generator.*

Amperes Excitation.	E. M. F.	Terminal Voltage.	Terminal Voltage Calculated by Institute Rule.	Regulation per cent.	
				Observed	Calculated by Institute Rule.
20	1700	640	640	166	166
30	2250	1440	1520	56.2	48
40	2550	2030	2160	25.6	18
50	2775	2360	2500	17.6	11
60	2960	2600	2740	13.8	8.1
70	3140	2740	2920	14.6	7.55

of this machine is shown in Fig. 15. I want again to call attention to the fact that if these curves are checked by the two methods mentioned in this paper, we find that for 2-phase and 3-phase machines, the curve of the terminal voltage lies between the two curves termed the optimistic and pessimistic curves, while the single-phase load curves approach very closely to the pessimistic curve.



Single-Phase Regulation Curve.

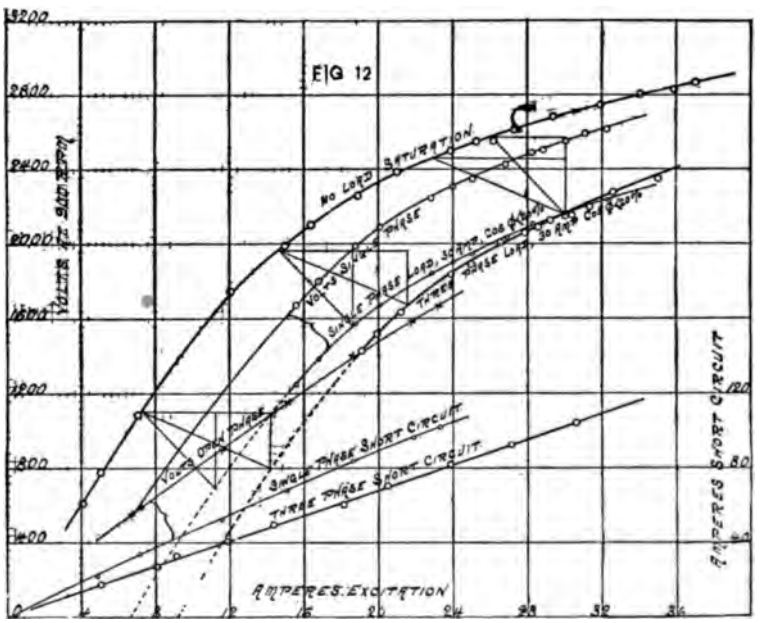
The data of Fig. 14 are represented in Table IV. which, after what has been said, requires little comment.

This table shows conclusively that on most modern machines the INSTITUTE rule gives results which do not at all correspond to actual observation.

It has been demonstrated by the large number of tests de-

scribed in this paper that the " ampere turn " method does not give satisfactory results in determining the regulation of an alternating current machine. The method is inherently wrong, as it neglects the extremely important inductive effect of local fields in the armature. It has also been shown that the e.m.f. method gives entirely misleading results. Therefore, it is proved conclusively that it is not possible to obtain the regulation of an alternating current machine by using no other characteristic than the saturation and short circuit curves.

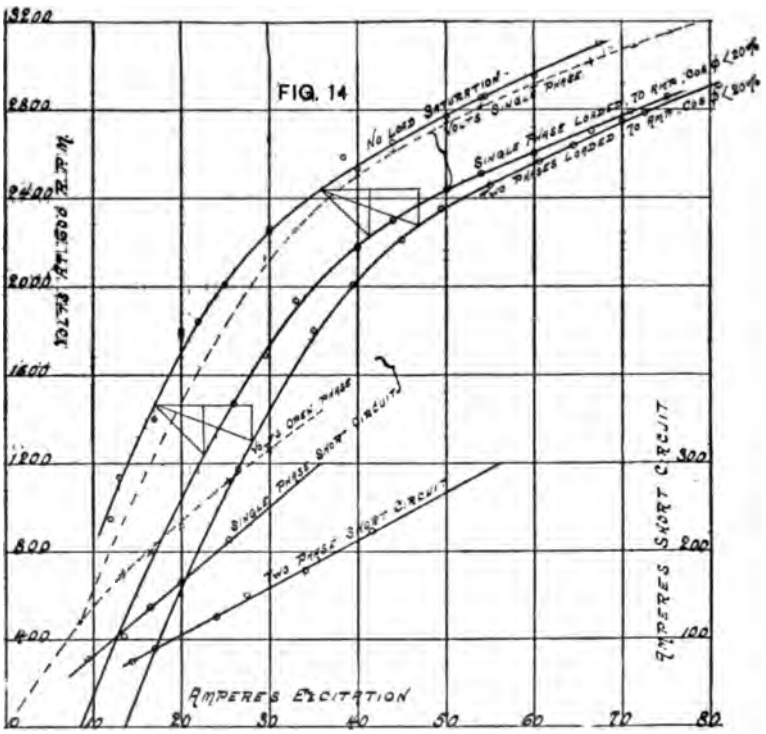
Another element is required in order to enable us to resolve all the effects of the armature current into two components, one com-



Regulation Curves on 100 k.w. 3-Phase Generator.

ponent representing the demagnetizing effect of the armature, and the other component representing the inductive drop produced by local armature fields. Any theory which aims at a complete explanation of the phenomena produced by a load in the armature of alternating current machines must conform to actual observation and fact. Therefore, the two methods which have been criticised in this paper stand condemned. They should not be used for the quantitative determination of the regulation, because they do not explain nor express the facts. We must frankly admit the existing predicament that there is no simple

method which explains all the facts observed, although the designer undoubtedly creates for himself an empirical method by which he can, within very close limits, determine the actual regulation without every time actually performing the experiment. It is entirely a matter of skillful designing to reduce the inductive drop in a machine. It is plain that it is necessary to avoid any leakage from pole to pole and for that reason it is essential to use large pole pitches; in other words, to place the poles far apart from one another. This matter of field leakage is



well brought out by a comparison of the regulation curves of the inductor generator in Fig. 1 with the regulation curves represented in the other figures. The poor regulation of the inductor generator is due to the field leakage between two inductor horns producing a counter e.m.f. Speaking from a large experience in the designing and testing of this type, I venture to assert that it is impossible to make these machines so that the load regulation curve lies very much above the pessimistic curve. While it is perfectly possible to build inductor generators with good regula-

tion, this can be done only at the expense of a great deal of material, which fact condemns this type not only from a commercial standpoint, but especially from the point of view of the scientific engineer, whose aim it must be to design machines of excellent properties with the least expenditure of material.

In looking at Figs. 10, 11, 12 and 14, in which the drop in the armature has been resolved into its two components, it is seen at a glance that if we want to take advantage of the high saturation it is essential to reduce to a minimum the local fields in the armature, as this reduces the side of our triangle parallel to the

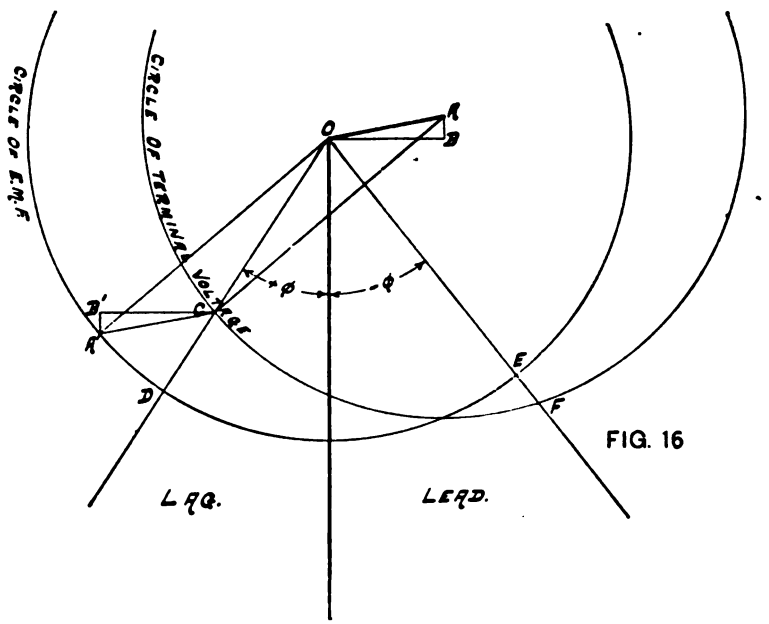


FIG. 16

Kapp's Diagram for the Determination of the Regulation at Different Power Factors.

ordinate. As a matter of design, this can be accomplished by using a large pole pitch, a narrow armature, and, to some extent, a large number of slots per pole and per phase. The large pole pitch which thus proves so useful has the further advantage of improving the ventilation of the machine, thus leading to cool operation. A large pole pitch makes a machine easily accessible, and increases the radiating surfaces, as the most effective part of the radiating surface of the machine lies in the armature faces.

If, for a given excitation, we have determined the drop of a machine for a given current and zero power factor, we can determine the regulation for any power factor for the same current, by using the vector diagram. The most elegant method is that represented in Fig. 16, originated by Mr. G. Kapp. After resolving the inductive drop into its two components, the armature reaction and the local fields, we can compose the ampere turns on the fields, O A′, with the ampere turns on the armature, O A, finding the resultant ampere turns O C. Next, applying the same process to the local fields, we can draw another diagram, making O B equal to the e.m.f. produced by these local fields, B A equal to the ohmic drop in the armature, and O A, equal to the e.m.f. of the machine produced by the resultant ampere turns. We thus obtain O C, the terminal voltage of the machine. It can readily be seen that, by describing the two circles with O A′ as radius, about O and A as centers, the *radii-vectores* drawn from O as center at an angle $+\varphi$ or $-\varphi$, will intersect the circle of terminal voltage in points C and F, so that O C and O F represent the terminal pressures at the two different power factors. The quadrant on the left represents a lag of the current, and therefore, a drop in pressure, while the quadrant on the right represents a lead. If the lead increases beyond the point of intersection of the two circles, the terminal pressure rises above the e.m.f. of the machine. For most practical purposes it is not necessary to use this diagram twice for the ampere turns on the armature and for the local fields, but it is sufficiently accurate to consider the inductive drop as an apparent impedance and to make O A equal to this impedance.

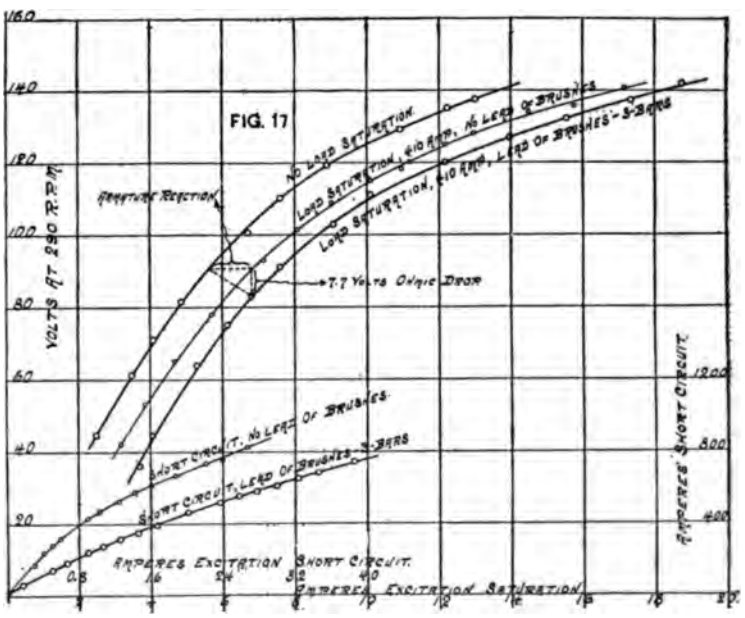
It should not be overlooked that the apparent impedance is not only dependent upon the field excitation, but it is also dependent upon the armature current. This can easily be seen by working out a few values for the apparent impedance in Fig. 4. It will thus be found that the impedance, while a constant at low saturation, increases rapidly with the increase of the armature current at the same field excitation.

It is interesting to study the curves giving the pressure on the open phase while taking out single-phase current, as this has important bearing on the question of regulation of 2-phase and 3-phase machines when operating on a lighting load. It can be seen from Figs. 9 and 12, which represent 3-phase machines 2 phases in series loaded, the third phase open, that for high saturation the curve for the pressure on the open phase between

the terminal of the open phase and either of the terminals of the loaded phases lies considerably higher than the curve for the pressure on the loaded phases. The same is true to almost the same extent of the 2-phase machine, the curves of which are represented in Fig. 14. This shows conclusively that there is little preference in favor of either type of machine as far as regulation is concerned.

General Remarks Regarding the Value of the Short Circuit Characteristic in the Design of Electric Generators.

While the use of the short circuit characteristic is thus greatly invalidated by the difficulty of separating the effects of armature



reaction and of the local fields, it yet remains a valuable characteristic of the machine. It has been shown conclusively in this paper that we cannot use the saturation and short circuit curves alone to determine the regulation of a machine; but it has been indicated that, by plotting from these two curves, two other curves which I termed the " optimistic " and " pessimistic" regulation curves, it is possible, with a certain degree of accuracy, to plot the actual regulation curve between these two last named curves. In doing this, there is, of course, much left to the discretion and judgment of the designer, who, nevertheless,

derives a great deal of help from these curves. The work of designing is more a work of art than a work of science. It is true that sound, scientific knowledge is absolutely required, but scientific knowledge without engineering intuition avails very little and leads merely to abortive designs. The great designers in electrical engineering have not always clearly understood why they have designed a machine in a certain way. They have been guided less by science than by intuition.

The short circuit characteristic can be very usefully applied to the regulation of direct current generators, thus supplying a means of finding the ampere turns necessary to compound or over compound a machine. Although somewhat foreign to our subject, there are shown in Fig. 17 the saturation, short circuit and regulation curves of a 75 k.w. direct current generator. There are plotted in this figure the saturation curve at no load, the load saturation at 410 amperes with no lead of brushes, and the load saturation at 410 amperes with a lead of brushes equal to three bars. There are also plotted two short circuit curves, one with no lead of brushes, and the other with a lead of three bars. These short circuit curves have been obtained by separately exciting the generator and short circuiting the armature. The difference between the ampere turns required with lead and without lead of brushes at 410 amperes in the armature corresponds to the armature reaction of the machine. It will be found that with no lead of brushes, the distance between the no load and load saturations measured along the ordinate are the same for any saturation, while we can easily determine the load saturation with a lead of three bars, by combining the armature reaction and the ohmic drop in the armature as shown in Fig. 17. The short circuit test on direct current machines has the further advantage that it is a rather severe test for commutation, requiring very little power for driving. This method has been used by the writer for testing very large direct current machines which could not be operated in the testing room under full load. A machine which commutates satisfactorily in short circuit will surely commutate satisfactorily at full load.

SUMMARY.

To sum up the results of this paper: It has been demonstrated that the application of the ampere turn method, as proposed by the INSTITUTE rules, leads to entirely wrong results. It makes machines of inferior design and large leakage appear in regulation

not only equal to, but even better than, machines of careful and superior design. In a word, the method is not scientific and not in accordance with fact and observation.

The ampere turn method, while very simple is inherently wrong, and it should, therefore, not be used, even if it is impossible to substitute an equally simple rule for it. The desire to have such a simple rule should not tempt us to adopt one that is false. There is a tendency among engineers to neglect the element of uncertainty which is so prominent in all engineering questions.

In conclusion, I wish to thank Mr. T. S. Allen, one of my assistants, for the pains he has taken in plotting the curves presented in this paper.

POSTSCRIPT.

In my paper on " The Experimental Basis for the Theory of the Regulation of Alternators," which I presened at the 177th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, New York, May 19, 1903, I gave experimental data with a view to checking the two most prevalent methods for predetermining the drop in alternators. The conclusion at which I arrived from my tests is that we obtain the most satisfactory agreement between calculation and experiment if we resolve the effect of the armature into armature reaction and local armature fields. As my paper dealt only with the experimental side of my subject, I neglected to call attention to a valuable paper on this subject by Prof. A. Potier of Paris, which appeared in *L'Eclairage Etectrique*, July 28, 1900, entitled " Sur la Reaction D'Induit des Alternateurs." There is an abstract of my paper before the INSTITUTE published in *L'Eclairage* of Jan. 9, 1904, in which it is correctly pointed out that the method for determining the regulation at low power-factor, which seems to agree most closely with fact and observation is the method which was pointed out by Mr. Potier in the paper which I have quoted. My omission to refer to Professor Potier's paper is all the more inexcusable as Professor Potier had the courtesy of sending me at the time a copy of his paper. I exceedingly regret my negligence in not referring to Professor Potier's article in my paper, and I wish therefore to direct attention to it in this note.

A paper read at the 177th Meeting of the American Institute of Electrical Engineers, New York, May 19, 1903.

A STUDY OF THE HEYLAND MACHINE AS MOTOR AND GENERATOR.

BY COMFORT A. ADAMS.

The Heyland motor consists essentially of an induction motor with short circuited secondary, and a commutator by means of which exciting current may be supplied either to the short circuited winding or to a separate exciting winding. With either form, the power-factor can be controlled by means of the current sent in through the brushes.

INTRODUCTION.

The experimental work which forms the basis of this paper was carried on during the early part of last summer in connection with an experimental machine built by the General Electric Co., and kindly loaned to the writer. The work was first undertaken by two of the senior students in Electrical Engineering as a thesis, but owing to the shortness of the time at their disposal, very little was accomplished. The writer, having become interested, then undertook the work on his own account.

The machine tested was not of the exact type advocated by Mr. Heyland, and consequently the results will not have the same directly practical value. The work was however intensely interesting to the writer, and if his interest in the interpretation of minor phenomena has carried him beyond those having practical value, he asks pardon and can only hope that the results here recorded may be of some value to those working along similar lines.

Before proceeding to the discussion of the particular machine under consideration, it may not be out of place to review briefly the history and general theory of the subject.

If any stationary closed coil direct-current armature such as a Gramme-Ring armature, be supplied with p symmetrical poly-

phase currents through p brushes symmetrically placed around its commutator, there will be produced a magnetic field which revolves around the periphery of the armature with an electrical angular velocity equal to $2\pi n$, n being the frequency of the impressed e.m.f. If now the armature be revolved while the brushes remain stationary, the space velocity of the revolving field will remain the same, since the points at which the currents enter the armature are stationary. We have an exactly analagous case in every direct-current armature supplied with a continuous current through stationary brushes, the m.m.f. of this current remaining stationary in space, no matter at what speed the armature may revolve.

As the space direction of the armature reaction in this latter case depends upon the position of the brushes, so does the space-phase of the revolving field in the alternating current case. The usefulness of this arrangement, however, depends upon the fact that when running at synchronism, the total reactance of the winding drops to a very small quantity, provided that p, the number of phases is relatively large, and, under the same conditions, the sparking at the brushes is very light.

By this means it is possible to supply the exciting current of a polyphase motor or generator by means of the polyphase currents delivered to or by the machine in question, without sacrifice of power factor; in fact, when applied to an induction motor, the current taken may be made by over-excitation to lead the impressed e.m.f.

The principle described above was first employed by Görges[1] in 1891, in a polyphase series motor, the stationary part of which was fitted with the ordinary polyphase windings, such as used on an alternator armature, or on the stator of an induction motor, and the rotating part of which consisted of a direct current armature with commutator and brushes, as above described, the two windings being connected in series; see Fig. 1.

This was merely the application of the revolving field idea to the old single-phase series motor, its chief advantage over the latter being the high power-factor and the reduction of the sparking at synchronism.

At other speeds, however, the sparking is serious, due to the currents induced in the short circuited coil by the slip e.m.f., and

1. *Elektrotechnische Zeitschrift*, Dec. 25, 1891. The revolving brush motor of Le Blanc (Comptes Rendu, July 29, 1889), involves the same general principle, but applied in a different way, the object being to make the motor self starting rather than to improve the power factor

as the series motor is not a constant speed motor, Görges' machine found no commercial field of usefulness. In other respects than those mentioned, the behavior of this machine is exactly similar to that of the single-phase series motor.

The advent of the induction motor turned the attention of investigators from the commutator motor, and five years elapsed before Blondel[1] described a very interesting though complicated combination of the commutator and induction motors.

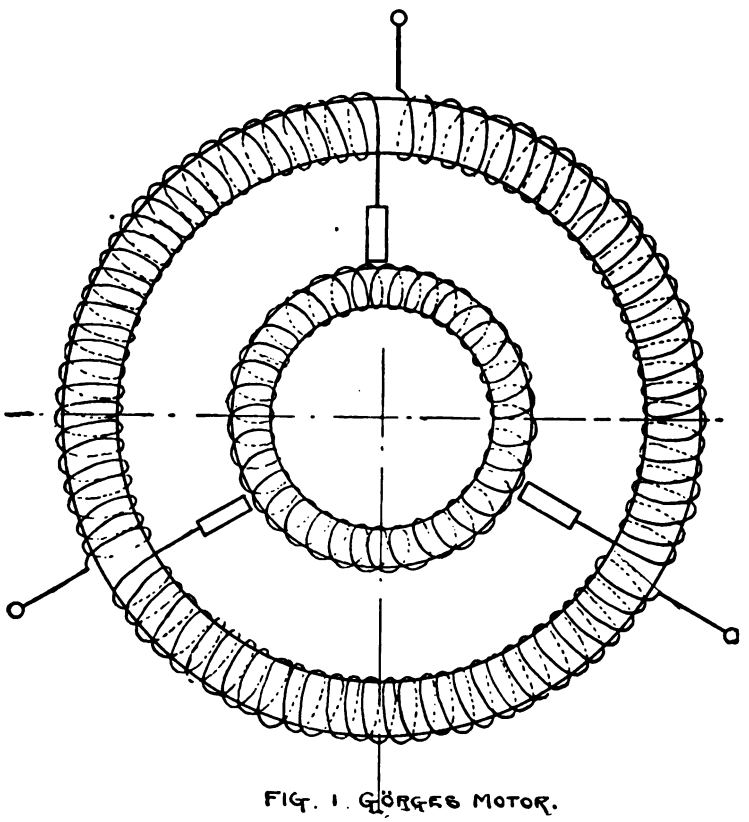


FIG. 1. GÖRGES MOTOR.

It consisted of an ordinary induction motor with short circuited secondary and an additional closed coil direct current rotor winding with commutator. This latter winding was supplied with continuous current through a pair of brushes revolved at primary frequency by means of a synchronous motor.

This motor is said to have operated perfectly without sparking, and with a power factor entirely within control by means of the

NOTE 1. (*L'Eclairage Electrique*, Aug. 29, 1896).

continuous exciting current. Theoretically, there is every reason to believe that it should so operate, owing to the long commutation cycle. In other respects than that of commutation the Blondel motor is exactly similar to one of the forms suggested by Heyland, in fact to that form the tests of which are recorded in the following pages, and so far as the compensation for wattless current is concerned, the theory given below of the Heyland motor applies strictly to Blondel's motor. In both motors the field produced by the exciting current revolves synchronously; in the Blondel motor it is produced by a continuous current led in through synchronously revolving brushes, whereas in the Heyland motor it is produced by a synchronous alternating current led in through stationary brushes.

The necessity for a direct-current supply, a synchronous motor and revolving brushes, easily explains why the Blondel motor was never considered commercially.

Considering the short step from this to the Heyland motor, it is strange that another five years elapsed before the latter was announced.[1]

The Heyland motor consists essentially of an induction motor with short-circuited secondary, and a commutator by means of which exciting current may be supplied either to the short-circuited winding or to a separate exciting winding. With either form, the power factor can be controlled by means of the current sent in through the brushes.

The two original forms[2] are illustrated diagrammatically in Figs. 2 and 3. In both cases the primary is that of the ordinary induction motor, and the brushes are connected either to the supply circuit in shunt with the primary or to the secondary of a step-down transformer. In Fig. 2 the secondary consists of a direct current closed coil winding with non-inductive resistances inserted between adjacent commutator bars, which resistances close the circuits of the individual coils and cause them to act as the short circuited secondary of the ordinary induction motor.

Another important function of these resistances is to receive the commutation kick of each coil as it passes a brush, and thus to minimize the sparking tendency.

---

1. *Elektrotechnische Zeitschrift*, Aug. 8, 1901.

2. Mr. Heyland is still experimenting with numerous varieties of windings, some of which have been recently described, see *E. T. Z.*, 1903, Jan. 22d, Jan. 29th, Feb. 5th, March 19th. These differ, however, so materially from the type tested that they will not be here considered.

But these resistances have still a third function, namely that of distributing the exciting current in the several coils of the rotor in such a way as to avoid the harmonics of the three belt winding.

Fig. 3 shows the second type, which was that tested by the writer. The short-circuited secondary is in this case a squirrel cage shown in the tops of the rotor slots, and the separately excited winding is shown in the bottoms of the rotor slots. The rotor windings are exactly similar to those of the Blondel motor. This

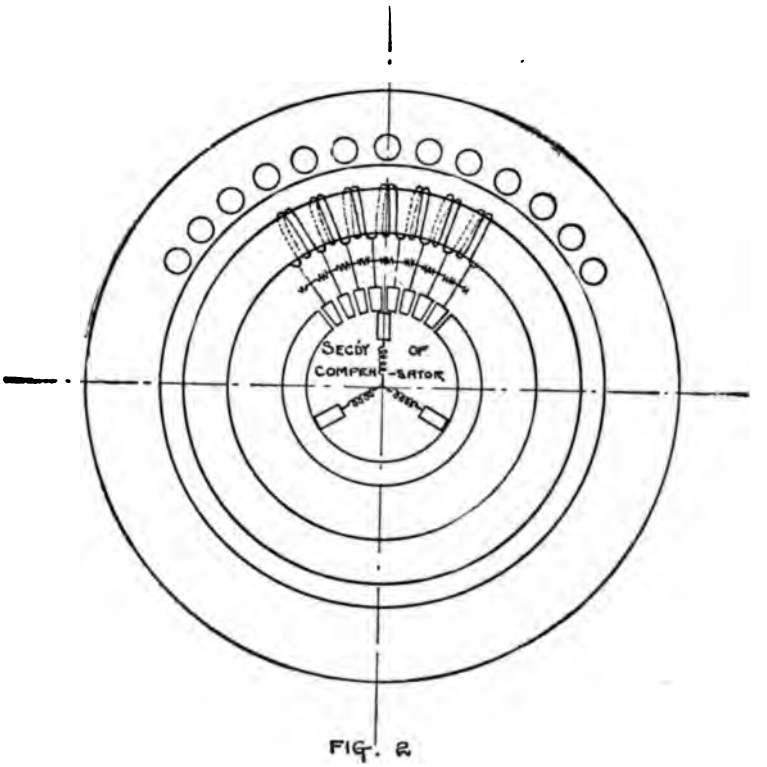


FIG. 2.

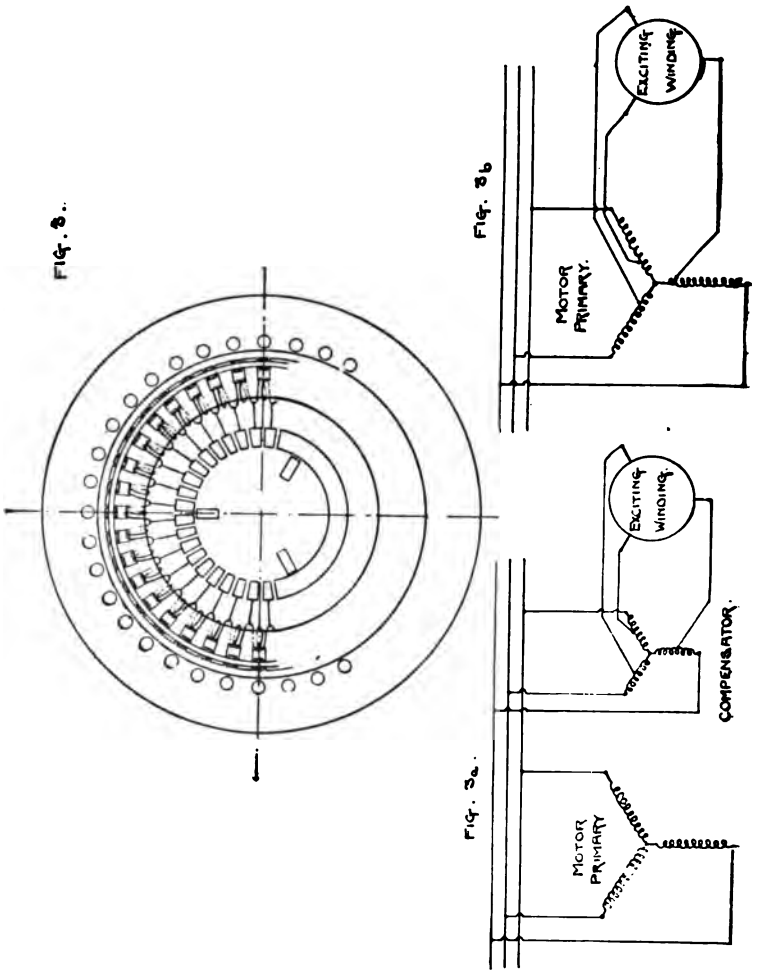
type has many points in common with that shown in Fig. 2, the chief difference being in the matter of commutation.

Heyland also pointed out in his first communication that his machine would operate very satisfactorily as a self self-exciting alternator.

Shortly after the announcement of the Heyland motor, M. Latour[1] described a machine just like that of Fig. 3 without the squirrel cage, but intended primarily as generator. The only

1. *L'Industrie Electrique*, 1902, Feb. 25th, April 10th, April 25th

difference between this and the Görges machine is that. in the former, the armature is connected in shunt, and in the latter case in series with the field. Although there is no path especially provided for the slip current in the Latour machine, the armature current is closed through the supply circuit, and slip currents do flow along this path as will be shown below.



More recently Osnos[1] has described a machine in which the alternating exciting current is first commutated by means of a small auxiliary direct current armature on the shaft of the main machine, and then led into the rotor exciting winding by means of slip rings.

1. (*E. T. Z.*, Oct. 16, 1902.)

Reactance of Exciting Winding.

In the calculation of any such machine it is necessary to know what is the effective reactance of the exciting winding. This problem, and the one of commutation in the same class of machines, are closely allied, and have been much analyzed by various writers.[1] The solutions obtained have differed very widely. Accurately analyzed for an actual machine, the problem is a serious one, but it is not difficult to get a general view of the more important factors and the manner in which they enter.

Consider first a machine without the short circuited secondary, such as that of Latour or Görges, and assume that the armature is running at synchronism.

The total flux linked with the armature or secondary winding, or any part of it, may be divided into two parts, the *mutual flux* linked with both primary and secondary and the *secondary leakage flux*. Consider first the mutual flux; in case of a large number of phases supplied with symmetrical, simple harmonic e.m.f.'s, this will consist of a sinusoidal field revolving at synchronous velocity. Therefore, since the armature is also revolving in synchronism, there is no relative motion between the two and no corresponding reactance e.m.f. If however the number of phases be small, as is usual, say three, then the armature will be a three-belt winding, and there will be introduced into the revolving field several prominent harmonics revolving at submultiples of the synchronous velocity. These harmonics will give rise to a reactive e.m.f. which decreases as the number of phases increases. There is another harmonic introduced by the teeth, but this is usually made negligible in any set of coils by the vernier action of the stator and rotor slots.

Consider now the *leakage flux:* the corresponding reactance is evidently determined by the frequency of the current in the circuit in question; but although the average current in any individual coil is of slip frequency, the circuit in question is that between two adjacent brushes, the current in which is of primary frequency.

The current variation in the coil undergoing commutation does not affect the reactance, since the commutation is forced and

1. Le Blanc, *L'Eclairage Electrique*, Oct. 26, 1901.
Latour, *L'Eclairage Electrique*, Nov. 23, 1901.
Heyland, *L'Eclairage Electrique*, Nov. 30, 1901.
Poincare, *L'Eclairage Electrique*, Jan. 18, 1902.
Latour, *Electrical World and Engineer*, Feb. 1, 1902. Many of the references given elsewhere in this paper include discussions of these points.

represents a slight increase in the energy component of the e.m.f. rather than in the reactive component. The leakage reactance is thus determined by the primary frequency.

Commutation.—The conditions for ideal commutation are, as in the case of a direct current machine, that the flux linked with a coil should remain constant during its commutation period, and that the brush-contact resistance should be high relatively to that of the coil.

The second condition is as easily fulfilled in the alternating as in the direct current machine, but not so with the first. At synchronism there is no relative motion between the fundamental field and the coil in commutation, but there is a considerable relative motion between this coil and the harmonic fields, which, in the case of a three-phase armature, is the cause of heavy currents in the short circuited coil and sparking at the brushes.

The tooth harmonics may also be of considerable magnitude in the case of a short air gap and open slots, see Fig. 4*g*, described below. The resistance to commutation offered by the leakage reactance is the same as in a similar direct current machine, but here it is not possible to neutralize this effect by shifting the brushes. This is however of little importance as compared with the first mentioned harmonics. The ordinary devices for the suppression of sparking will be helpful here, but not so effective, owing to the greater e.m.f.'s in the short-circuited coil.

The above applies primarily to a secondary consisting simply of a closed-coil direct-current armature. In Heyland's motor, Fig. 2, the non-inductive resistances between bars serve as a means of distributing the exciting current so as to eliminate the harmonics otherwise due to the wide phase belts, even in the case of single-phase excitation. These resistances also receive the commutation kick due to the leakage reactance.

The squirrel cage in Fig. 3 serves the same purpose, but not so perfectly. Here the field harmonics are largely eliminated by the damping effect of the low resistance squirrel cage, or, the m.m.f. harmonics due to the nature of the exciting winding are balanced by secondary currents in the short-circuited rotor winding. This in fact is the explanation of the action of the machine shown in Fig. 2, the induced currents and the exciting current combining in the same winding to produce a sinusoidal m.m.f. distribution, whereas in the machine of Fig. 3 they are in separate windings. The less satisfactory commutation in the

latter case is due partly at least to the leakage between the two secondary windings.

The remarks above concerning reactance and commutation apply only to synchronous operation. Whenever there is slip, there will be a slip e.m.f. and current in the short-circuited coil, which, in the case of the simple closed-coil winding, or in the machine of Fig. 3, will tend to cause sparking. In the machine of Fig. 2, most of the slip current will be shunted across the commutator bar-connections with which the brush is in parallel. But if the slip is large, sparking will occur even here. There will also be a slip current in the main part of the exciting winding, which in the two first mentioned machines will flow through the brushes into the supply circuit. In the machine of Fig. 2, a large part of this slip current will be shunted through the non-inductive bar-connections.

Practically the same thing takes place in No. 3, for with a given *total* slip current, most of it will flow in the low-resistance squirrel cage, and only a small part through the exciting winding and brushes.

In either No. 2 or No. 3 when running normally, the amount of slip current that flows through the brushes does not add seriously to that otherwise necessary, especially as it is in quadrature with the exciting current. Neither does the slip e.m.f. in the short circuited coil endanger the commutation, provided the ordinary commutation precautions have been observed. But when starting, or running at very low speeds, both of these disturbances are considerable.

The effect of the leakage reactance of the exciting winding of either of these Heyland machines is practically negligible. In No. 3 the presence of the low-resistance secondary reduces the apparent reactance of the exciting winding; this is shown for the machine tested in Figs. 18 and 19, where the power factor of the exciting current approaches unity when the slip approaches zero. In the machine of Fig. 2, the independence of the individual coils tends to reduce the current therein to the slip frequency. This is readily seen from the curves of Fig. 4, which show the current variation in single coils of the exciting winding of a machine without any commutator bar connections. Curves (*a*), (*b*) and (*c*) are for three different coils of a three-phase machine at synchronism and (*d*), (*e*) and (*f*) for single, three and six phase machines respectively, each with a considerable slip.

Fig. 4*g* is an oscillograph curve of the potential difference

between two adjacent commutator bars of the machine tested, while running under full load. The long wave, only a small fraction of which is shown, is of slip frequency and shows the

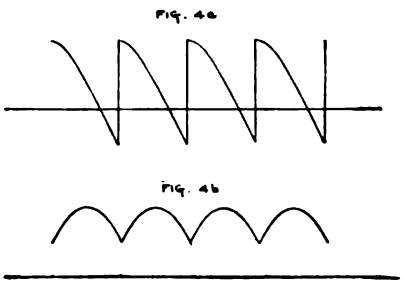
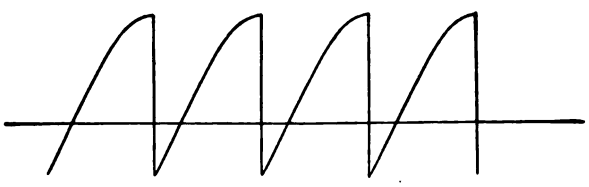
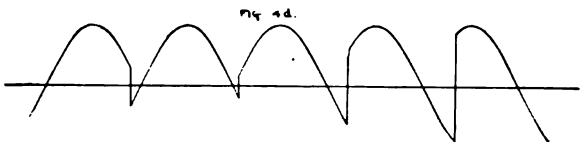
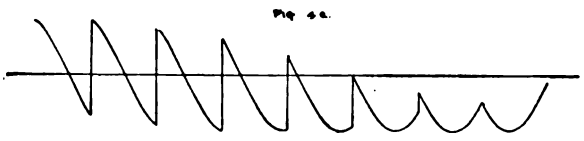
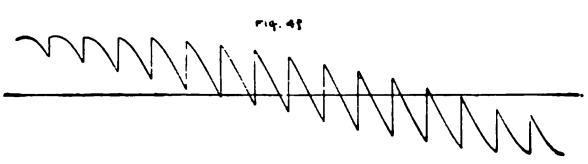


Fig. 4c.









average current; the large kinks are due to the commutation or the shifting of the coil in question from one phase to the next; and the small kinks are due to the teeth. But for the tooth

harmonic, this curve would look very much like that of Fig. 4*c*. Each of the curves *d*, *e* and *f*, may be considered as approximately made up of a long slip wave, and a very prominent harmonic of about *p* times the primary frequency, where *p* is the number of phases. If however the coil in question is more or less independent, as in the machine of Fig. 2, these harmonics will be largely damped out, leaving only the main exciting current of slip frequency. This is what was referred to on page 764 as the distributing function of the commutator-bar connections and is also a statement from a different point of view, of what was said at the bottom of page 768 regarding sinusoidal m.m.f. distribution.

Description of Machine Tested.

As the analysis given below relates primarily to the type of machine tested, it will be well to get that machine clearly before us. It was a ten h.p., three-phase, 440-volt, 60-cycle, 6-pole

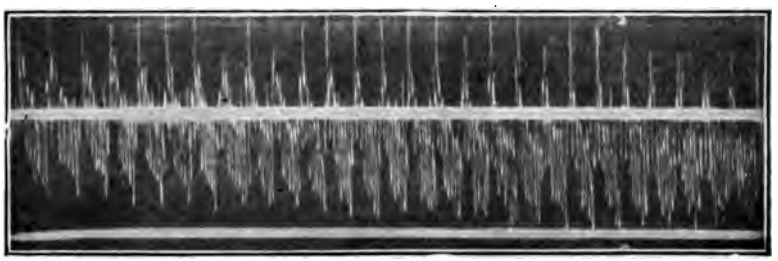


Fig. 4g.

induction-motor (see Fig. 5), with a low-resistance squirrel cage in the bottom of the rotor slots, and a separate exciting winding in the tops of the rotor slots.

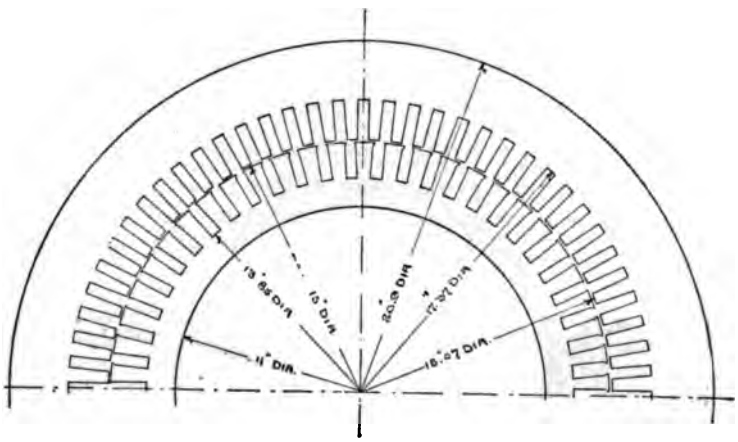
The exciting winding was of the ordinary two-path or series variety, connected to a 107-bar commutator, and as there were 54 rotor slots, one-half slot was empty. But the real number of bars was only 35, or about 6 per pole, since the commutator leads were disconnected from two of every three bars, and the three bars soldered together. There were thus 33 sets of three coils each and two sets of four coils each.

The brushes were of copper gauze, two sets of three each, each set being provided with an independent rocker. After some preliminary tests, these rockers were graduated in electrical degrees with arbitrary zeros.

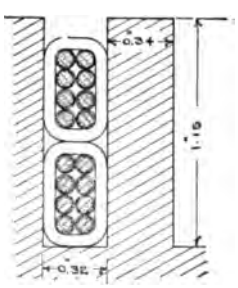
The remaining dimensions are given in Fig. 5, except the

length of core parallel to the shaft, which is five inches between heads. The primary is star-connected, and has a hot resistance, $r_1 = .75$ ohms per phase, and a leakage reactance $x_1 = 1.$ ohm per phase.

The squirrel cage has an equivalent hot resistance of $r_2 = .43$ ohms per phase (reduced to primary turns), and an equivalent



STATOR SLOT.
16 CONDUCTORS No 11. B&S.



ROTOR SLOT.
WOUND — 24 CON. No 16 B&S
SQUIRREL-BAR . 0.5 X 0.32

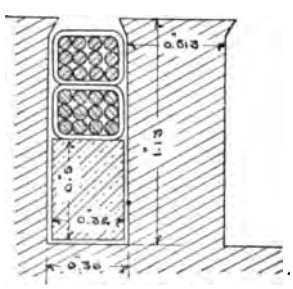


FIG. 5

leakage reactance with respect to the primary of $x_2 = 1.88$ ohms. $x_1 + x_2$ was measured at standstill and the two separated by calculation. X_1 is larger because the squirrel cage was concentrated in the bottoms of the slots, and because of the overhanging rotor teeth.

The extra exciting winding, when supplied with 3-phase excitation through 3 brushes at intervals of 120 electrical degrees, is delta-connected and a three-belt winding, whereas the primary is a six-belt winding; *i.e.*, in the ordinary 3-phase winding there are six phase-belts per pair of poles, the currents in any two adjacent belts differing in phase by 60°, whereas in the closed-coil direct-current winding, there are only three phase belts, the currents in which differ by 120°. This is an important distinction since both in the generation of e.m.f. and of m.m.f. by a three-belt winding, there is a considerable loss of effectiveness due to the breadth of each belt, and the consequent differential action going on between different parts of the same belt. The differential factor for a distributed six-belt winding in a sinusoidal field is $\frac{6}{2\pi} = .955$, that for a three-belt winding is $\frac{3\sqrt{3}}{2\pi} = .827$, and the differential factor of the latter with respect to the former is $\frac{\sqrt{3}}{2} = 866$.

The actual hot resistance per delta phase of this winding was 2.7 ohms, or reduced to star, .9 ohms.

The equivalent resistance per star phase reduced to primary turns and to a six belt basis is, $r_3 = 2.7 \left(\frac{72\times16}{53.5\times24}\right)^2 \left(\frac{2}{\sqrt{3}}\right)^2 = 2.9$ ohms. This is the resistance to be used in the calculation of the slip current in the exciting winding. The differential factor enters twice, since it affects both the slip e.m.f. induced in this winding, and the m.m.f. value of the resulting current as compared with the same current in the primary. This assumes a sinusoidal flux distribution, and neglects the resistance of the outside circuit through which the slip current must flow; it is therefore only approximate.

The equivalent leakage reactance of this winding reduced to primary turns is, $x_3 = .86$.

Its mutual leakage reactance with respect to the squirrel cage is only a little less than this.

As there will be slip current in both the squirrel-cage and the exciting winding, it will be convenient at times to treat them as a single winding in which case their equivalent hot resistance and leakage reactance[1] will be respectively (for slips within the working range) $r = .375$ and $x = 1.25$ ohms.

1. All the reactances are given reduced to primary frequency.

A rather interesting fact which has, however, no particular bearing on the subject of this paper, is that for low speeds, *e.g.*, at standstill, the equivalent resistance is considerably larger, and the reactance smaller, than that given above. If the copper were uniformly distributed throughout the slot section, this would not be the case.

Theory of Operation.

As in the induction motor, the magnitude and speed of the revolving field are, for any given machine, practically dependent upon the magnitude and frequency of the impressed e.m.f. In the particular machine under consideration, there are three windings and three distinct currents, the resultant m.m.f. of which must be just sufficient to produce the above-mentioned flux under all conditions, remembering of course that as the primary drop increases with the current, the counter e.m.f. and flux will decrease slightly.

The only difference between this and the ordinary induction motor problem is that here we have an additional externally supplied current and m.m.f. to take account of, one that revolves with synchronous velocity, if supplied from the same source as that of the motor current, but one whose space-phase with respect to that of the primary e.m.f. depends not only upon its time-phase but also upon the position of the brushes. It is possible, therefore, by means of the brushes, to give to the m.m.f. of this exciting current any desired space-phase with respect to the other m.m.fs. These relations will be more readily appreciated with the aid of a vector diagram.

The familiar induction-motor diagram is shown in Fig. 11. All secondary constants are reduced to primary turns. Φ is the flux common to both primary and secondary, $E'_1 = 4.44\, n\, \Phi_m\, N_1\, 10^{-8}$, that part of impressed e.m.f. necessary to balance the counter e.m.f., $-E'_1$; $E'_2 = -E'_1$, the e.m.f. that would be induced in the secondary at standstill; s the slip, and $s\,E'_2$ the slip e.m.f. in secondary; $I_2 = \frac{s\,E'_2}{\sqrt{r_2^2 + s^2\,x_2^2}}$ = secondary current; $I_1' = -I_2$, that part of primary current necessary to balance the m.m.f. of I_2;

I_0 = the exciting current.

$I_1\sqrt{r_1^2 + x_1^2} = I_1 Z_1$ = impedance drop in primary.

E_1 = vector sum of E'_1 and $I_1 Z_1$ = primary impressed e.m.f.

There are two distinct interpretations of this diagram, one according to which the directions of the vectors represent the

relative time-phases of the several variables, and the other according to which the directions of the vectors represent the relative space-phases, in electrical degress, of the same variables. Clear conceptions of both interpretations are necessary to a thorough understanding of the problem in hand, but the latter will be particularly useful, since it is the space-phase of the exciting current that is determined by the brush position.

The power aspect of the problem is also a vital one, in which connection the following notation will be used.

$P_1 = E_1 I_1 \cos \theta_1$ = primary impressed power per phase.

$P_1 = E_1' I_1 \cos (E_1' I_1) + I_1^2 r_1$.

$P_1 = E_1' I_1' \cos \theta_2 + E_1' I_0 \cos (E_1' I_0) + I_1^2 r_1$.

$I_1^2 r_1$ is the primary copper loss,

$E'_1 I_0 \cos (E'_1 I_0)$ the core loss, and

$E'_1 I'_1 \cos \theta_2 = E'_2 I_2 \cos \theta_2$

$$P'_2 = E'_2 I_2 \cos \theta_2 = \frac{s E'^2_2}{\sqrt{r_2^2 + s^2 x_2^2}} \quad \frac{r_2}{\sqrt{r_2^2 + s^2 x_2^2}} = \frac{E'^2_2 s r_2}{r_2^2 + s_2 x_2^2}$$

Since P'_2 is the power transmitted across the air-gap from stator to rotor by the revolving field, it is a measure of the torque and is in fact the torque in synchronous watts.

One of the factors of the torque is E'_2 which in any given case is directly proportional to the flux, and the other factor is $I_2 \cos \theta_2$, the component of the secondary current in quadrature with the flux. This latter component will here be called the torque current, and will be designated thus: $I_T = I_2 \cos \theta_2$.

In a rough analysis, the flux and E'_2 may be assumed constant and the torque proportional to the torque current, I_T. This will prove useful later.

Consider now the change necessary to be made in the induction motor diagram in order to adapt it to the Heyland motor, particularly to that form shown in Figs. 3 and 5.

In addition to the slip current I_{2s}, in the squirrel cage there will be a current I_3 in the exciting winding which results from the combined action of two e.m.fs., one a slip e.m.f. in phase with $s E_2'$ (in fact equal to $s E'_2$ if, as is the case, the constants of the exciting winding have been reduced to primary turns), and the exciting e.m.f., E_c, whose relative phase is determined by the

brush position. For convenience, this current will be looked upon as two separate currents, which would be produced by the above two e.m.fs. if acting separately. Designate the current produced by the slip e.m.f. by I_{2s} and that produced by the exciting e.m.f. by I_c. Then I_s, the actual current in the exciting winding is the vector sum of I_{3s} and I_c. These currents are all shown on the right hand side of Fig. 7. The total secondary current, I_2, both windings taken together, is then the vector sums of I_{2s} and I_3, or as will be found more convenient, the vector sum of I_s and I_c, where I_s is the total slip current.

If I_{2s} and I_{3s} had been calculated separately for the particular machine under consideration, I_{2s} would have been found to lag a little more than as drawn, and I_{3s} a little less, owing to the relatively greater resistance in the latter; but their vector sum would have been the same. It is quite as accurate then to con-

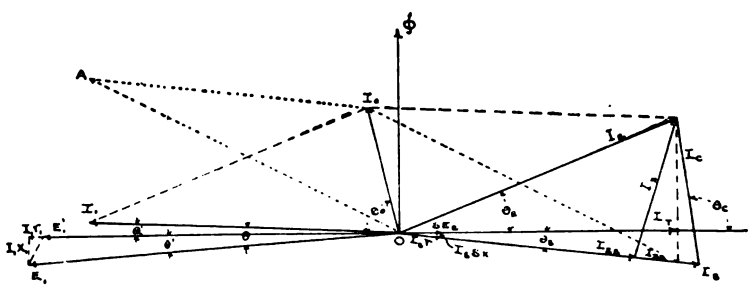


Fig. 7.
HEYLAND MOTOR.

sider these two windings as one, so far as the slip current is concerned, and to take the corresponding constants as given on page 773.

I_c is dependent entirely upon the exciting e.m.f. and the brush position. The reactance offered to this current is, as already explained, negligible, owing to the damping effect of the squirrel cage, and we may assume that I_c is in phase with E_c.

E_c is usually in quadrature with the impressed e.m.f., or at least bears a practically fixed phase relation thereto, being obtained from the same source by some transforming device.

Denote the space-phase of I_c by θ_c the angle which it makes with E'_2; this is not a fixed angle with fixed brush position, but nearly enough so for most calculations, and is far more convenient

than the angle between E_1 and I_c which is fixed with fixed brush position.

Assume now that the motor is running as an ordinary induction motor (see dotted lines of Fig. 7), on constant load. Then follow what takes place when a known exciting current I_c of known phase, θ_c, is delivered to the exciting winding.

The guiding fact in the determination of the new phase relations is that the torque current $I_T = I_2 \cos \theta_2$ will be practically unchanged. If θ_c is greater than 90° as in the figure, it is evident that I_s must increase beyond its corresponding value in a regular induction motor, *i.e.*, the slip must increase by an amount proportional to $- I_c \cos \theta_c$.

It is also evident that as the phase of I_2 is advanced by the introduction of I_c, the phase of I_1 will be similarly advanced, the amount of this advance depending upon $I_c \sin \theta_c$.

The exciting current has thus introduced two changes, one in the slip and slip current, proportional to $I_c \cos \theta_c$, and the other in the wattless component of I_1, proportional to $I_c \sin \theta_c$.

The latter change is evidently the important one, and to make it a maximum is to make the other a minimum, and $\theta_c = 90°$.

This is the usual arrangement. The effect of any change in I_c either as to its phase or magnitude is readily followed on the diagram. Results of tests in which various changes were made will be shown on a later page.

Of the two factors, magnetizing current and leakage drop, which go to introduce a wattless current in the induction motor, the former is approximately constant and the latter proportional to the load. It is thus impossible to compensate perfectly for primary lag at all loads, with a constant exciting current I_c. If I_c is just enough for no load compensation it will be insufficient at full load; if it just compensates at full load, it will over-compensate at no load and give a leading current.

The exciting current necessary for the complete compensation of this machine has been calculated for several loads and plotted in Fig. 8. One of the intermediate values of I_c will give a practically unit p.f. over the whole range except for very light loads. In this curve, as in later ones, the exciting current is plotted as it would be measured, amperes entering at one set of brushes, the theoretical ratio of this to the equivalent primary current is 1.79 and is obtained as follows:

One ampere from the compensator divides at the brush and becomes $\frac{1}{\sqrt{3}}$ amperes in each branch of the exciting winding.

This must be reduced to primary turns, and then by the differential factor, .866

$$\frac{1}{\sqrt{3}} \frac{24 \times 53.5}{16 \times 72} \times .866 = .557 \quad \text{and} \quad \frac{1}{.557} = .179$$

This calculation assumes sinusoidal currents and sinusoidal flux distribution in the air gap. Observations to be given below show that the real ratio is about 1.68.

Nearly all the points made in the above analysis, and some others, are illustrated in the tests recorded below.

General Conditions of Test.

Before considering the results of these tests it will be desirable to point out some of the conditions under which they were made.

The supply alternator was a General Electric 50 k.w. 3-phase 6 pole 60 cycle revolving-field machine with two slots per pole per phase. It is normally connected delta for 220 volts, but was connected star and raised to 440 volts for these tests. Its star e.m.f. is shown in Fig. 9_1.

The alternator was belted to an 80 h.p. single-crank, duplex-compound engine. The latter was new and its valves had never been accurately set, which aggravated the naturally large angular variation of this type of engine. This point was so forced upon our attention during these tests that later, when opportunity offered, the variation in velocity during a revolution when running light, was measured, and found to be about 3 per cent. on either side of the average.

The combined secondary resistance of the Heyland motor when running compensated, was so low that a very sudden change of 1 per cent. in the impressed frequency would have produced a change in the energy current amounting to about 60 per cent. of the full-load current.

After allowing for the various damping links between the engine and motor, there still remained a very annoying kick in the ammeter needles.

In addition to this rapid vibration of small amplitude, there

1. The fuzzy appearance noticed in this print is doubtless due to the warm weather and consequent fluidity of the damping oil, which allowed the oscillograph to inject a little of its own personality into the wave. It is safe to assume however that the longer kicks of larger amplitude, which appear in figure 4g have an entirely different origin.

was a larger swing of much longer period, due apparently to the sluggishness of the governor, and although the line voltage appeared to remain very constant, the exciting current as well as the primary motor current participated in the pumping.

Since the exciting circuit is almost a dead resistance, this was somewhat of a surprise, and the writer has looked in vain for a satisfactory explanation. The great steadiness of the line voltage and the comparatively slight flucutation of the wattmeter needles almost forces one to set aside the idea of a change of speed and an interchange of power between alternator and motor, and to look entirely to the motor itself as the origin of the difficulty.

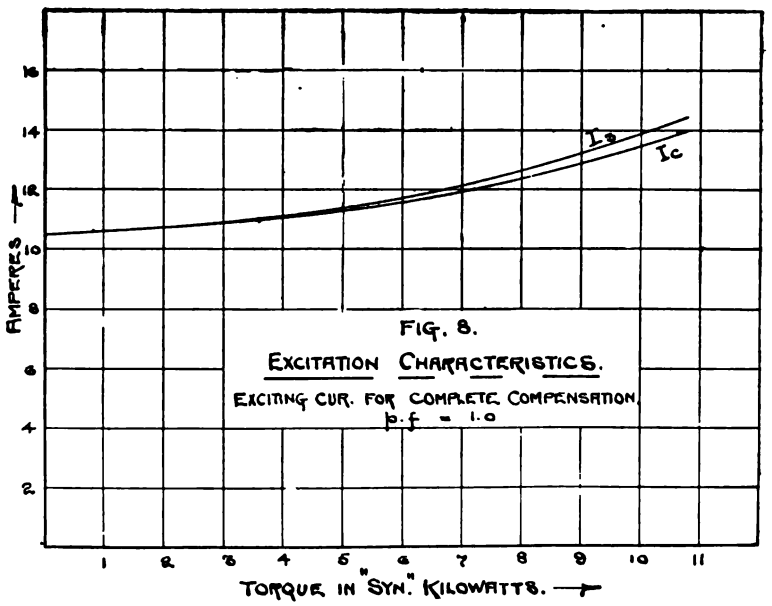


FIG. 8.

EXCITATION CHARACTERISTICS.

EXCITING CUR. FOR COMPLETE COMPENSATION. p.f = 1.0

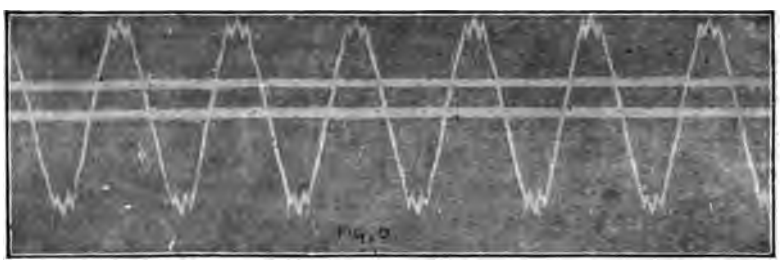
Whatever the cause, the exciting current did surge over a considerable range, and there was undoubtedly a corresponding change in power factor and line current, independently of any variation of the energy current; although that the latter did take place in a lesser degree was shown by the vibration of the wattmeter needles.

All these surgings decreased as the load increased, but varied from day to day, probably due to variations in steam pressure and belt tension. The latter was found by experiment to have considerable effect, but by no combination of conditions was it possible to eliminate the difficulty entirely. Another difficulty arose

from the heating of the exciting winding which caused the exciting current to decrease under constant exciting e.m.f. It was not possible to keep this current constant by means of an ammeter and rheostat, since the current in the ammeter includes a part of the slip current as above explained, and the latter varies with the load.

This variation of resistance was especially annoying in connection with the generator tests where the exciting current was necessarily much higher, and where a given change in resistance had a much more than proportional effect upon the terminal voltage.

The large exciting currents used in the generator tests gave trouble on another score, that of sparking; in fact, with any exciting current within the working range there was some sparking, but with the larger currents the sparking was so vicious as to require that the commutator should be turned down after a run



of a few hours. It is thus evident that the damping effect of the low resistance squirrel cage is not sufficient to warrant the use of copper brushes, certainly not with such a small number of commutator bars. Undoubtedly, the arrangement of Fig. 2 would operate much more satisfactorily in this respect.

The motor primary was star-connected and was provided with taps near the centre of the star, for excitation (see Fig. 3*b*).

There was also a separate star-connected compensator provided for the same purpose (see Fig. 3*a*). The latter was used in all the tests here described, as a much wider range of exciting e.m.fs. was thereby obtainable.

In all the motor tests there was an ammeter in each motor circuit and in each exciting circuit. Three wattmeters were used connected between the lines and the motor star, this arrangement better fitting the instruments at hand.

A single voltmeter was used across the line to maintain the

voltage constant, but the equality of the latter in the different phases was checked several times.

A single voltmeter and wattmeter were used in one of the star compensator circuits.

The slip was very accurately counted by the familiar alternating current arc lamp method.

The load on the motor consisted of a 500 volt direct current motor, operated as generator, and delivering current to a 500 volt generator as motor, on the shaft of the same engine to which the alternator was belted. This arrangement made it possible to obtain a very constant frequency, and very easy to control the load, although it undoubtedly contributed to the surging above described.

The instruments were frequently and carefully calibrated, and there is every reason to believe that the results are good for this class of work; but those who have had much experience in this line will appreciate the difficulties, especially when about twenty observations must be taken simultaneously by four or five observers. In this connection, the method above described for loading the motor had one great advantage, that it made it possible to keep the load perfectly steady throughout any desired period.

In all the motor tests the impressed e.m.f. was maintained at 440 volts.

Results of Tests.

Test No. 1.—The machine was run without compensation as an ordinary induction motor. The results are shown in Fig. 10.

A vector diagram drawn to scale for full load of 10 h.p. is shown in Fig. 11. This shows more clearly than the curves the phase relations of the severable variables, and the relative importance of the constants.

Test No. 2.—In this test the motor had no load except its own friction and that of the load-generator to which it was belted; the exciting e.m.f. was kept at an arbitrarily chosen value, 8.15 volts star, and the brushes shifted around a complete electrical circumference; readings were taken at regular intervals, the object being to find the magnetizing or normal position of the brushes, at which the power factor is a maximum and the line current a minimum. See Fig. 12.

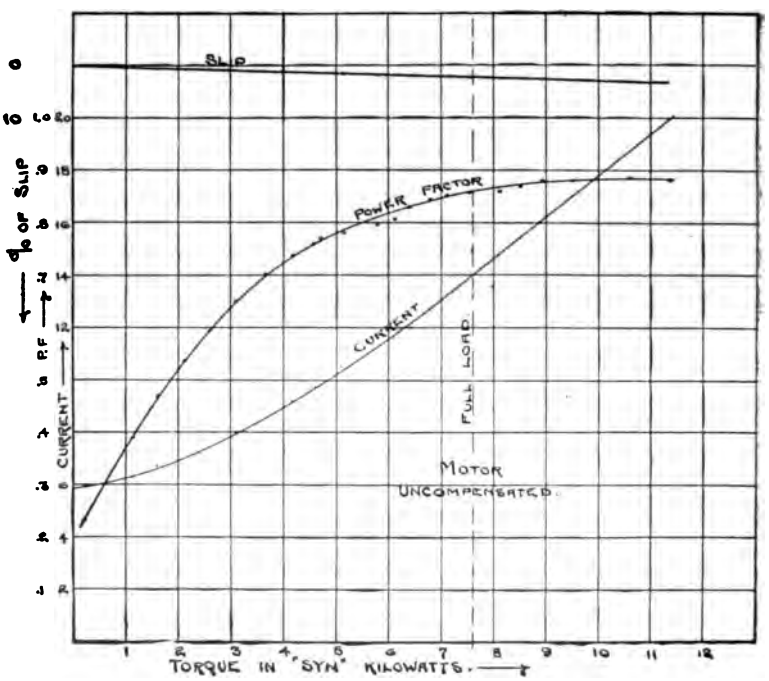
The observed points are marked and the solid curves are drawn in from approximate calculations in which the leakage reactances were neglected, the errors thereby introduced being compara-

tively small. The object of the calculations is that they may serve as a basis of interpretation for the observed results.

The broken curves, where drawn, are through observed points. The lower scale of degrees is the arbitrary one of the brush-rocker, and the upper degree scale corresponds to the angle θ_c of the diagrams.

The variation of the several quantities involved is most readily followed with the aid of the diagram, Fig. 13, which is drawn to scale. The notation is the same as in Fig. 7. I_o, I_T and I_c will

FIG. 10. TEST 71



be assumed constant but I_c may be shifted in phase by means of the brushes. The slip current is then $I_s = \bar{a}\bar{d} = I_T - I_c \cos \theta_c$ which in the position shown, is negative, *i.e.*, the motor is operating above synchronism. The primary current is $I_1 = \bar{d}\,\bar{f}$ and its power factor $= \cos \theta_1$ where θ_1 is the angle between $\bar{d}\,\bar{f}$ and the horizontal.

Of the total slip current a fixed proportion $\bar{a}\bar{b}$ flows in the exciting winding, and the remainder $\bar{b}\,\bar{d}$ in the squirrel cage. The total current delivered by the compensator is then the vector sum of I_c and $\bar{a}\,\bar{b}$, namely, $\bar{o}\,\bar{b} = I_3$. Given the slip current the slip may

be calculated as on page 1. It is easy now to follow the changes in the several variables, as I_c is made to revolve by shifting the brushes. The locus of the point b is shown by the inner curve in the diagram.

In calculating the curves for the slip and for I_3, the hot resistance of the squirrel cage was inadvertently used, whereas the current was so small that the squirrel cage was undoubtedly at a low temperature. Had the cold resistance been used, these two curves would have fallen nearer to the observed points.

The somewhat erratic disposition of the I_3 points is entirely accounted for by the change in temperature of the exciting windings; the points were not taken in consecutive order.

The considerable discrepancy between the calculated and observed values of I_1 and of the power factor, is partly due to the surging of the exciting current noted above, and partly to the

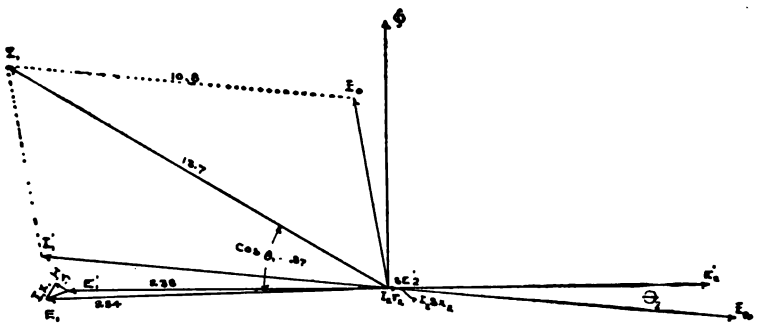


FIG. 11
SIMPLE INDUCTION MOTOR.

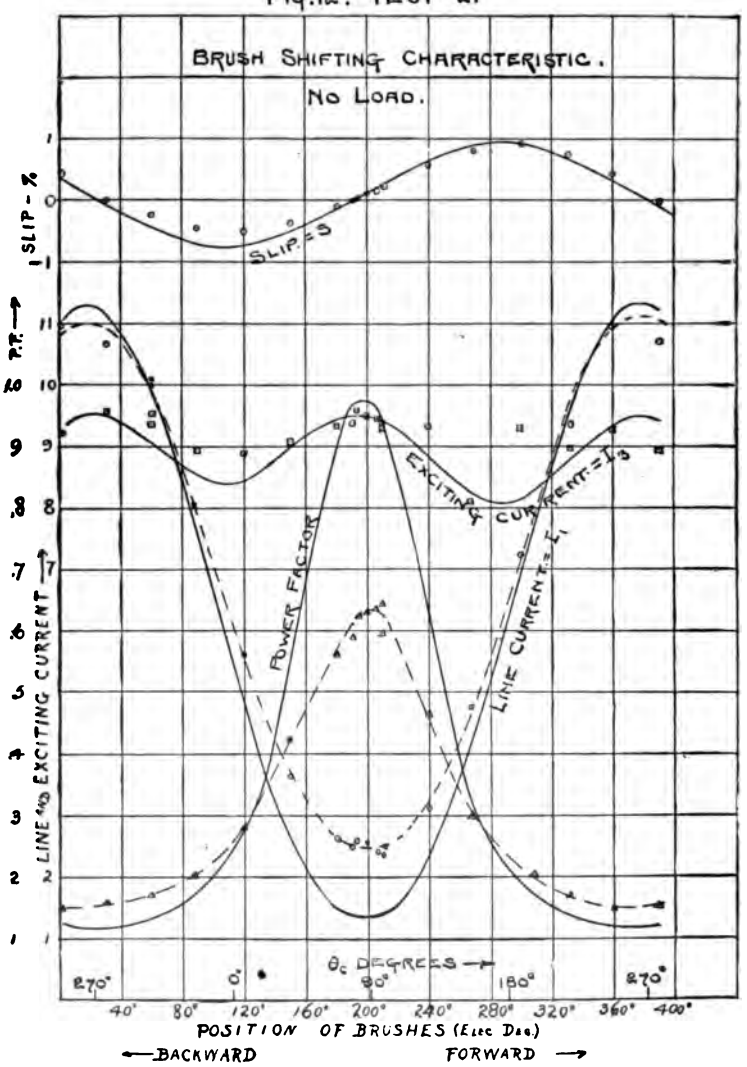
reaction of the three-belt exciting m.m.f. upon the primary current which introduces wattless harmonics into the latter.

Concerning the surging question, a consideration of Fig. 13 will show that when I_c is in the magnetizing position ($\theta_c = 90°$), a small change in I_c will make a large percentage change in I_1, and that if I_c is oscillating about a mean value, I_1 will oscillate about a mean value; but the mean value of I_c does not correspond to the mean value of I_1. If the mean value of I_c is small, *i.e.*, if the motor is under-excited, the mean value of I_c corresponds to something less than the mean value of I_1, and as the mean value of I_c increases, it corresponds to a value of I_1 which is less than its mean by an increasing difference, until the mean of I_c is equal to $I_0 \sin \theta_0$, when it corresponds to the minimum value of I_1.

If then the currents are surging as above described, and each

reading recorded is the mean taken over the range of oscillation, the records of I will be too large, the discrepancy being most marked in the vicinity of the highest power factor. The larger

FIG. 12. TEST 8.



the load the less this error, since an increase in energy component reduces the influence of the variable wattless component.

Concerning the wattless harmonics induced in the primary by the reaction of the exciting current, the simplest point of view is

to assume a sinusoidal flux distribution and to remember that the resultant m.m.f. of all three currents must be distributed sinusoidally. If one of the three is forced by the nature of its winding to give a very far from sinusoidal m.m.f., and if this one happens to be carrying a much larger current than the other two together, as is the case in hand, there will be induced in the other two windings, relatively large wattless harmonic currents, which neutralize the undesirable part of the exciting m.m.f.

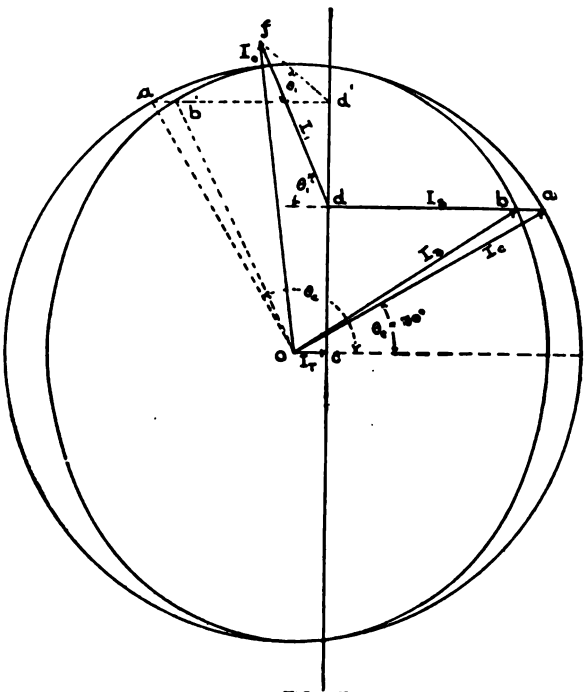


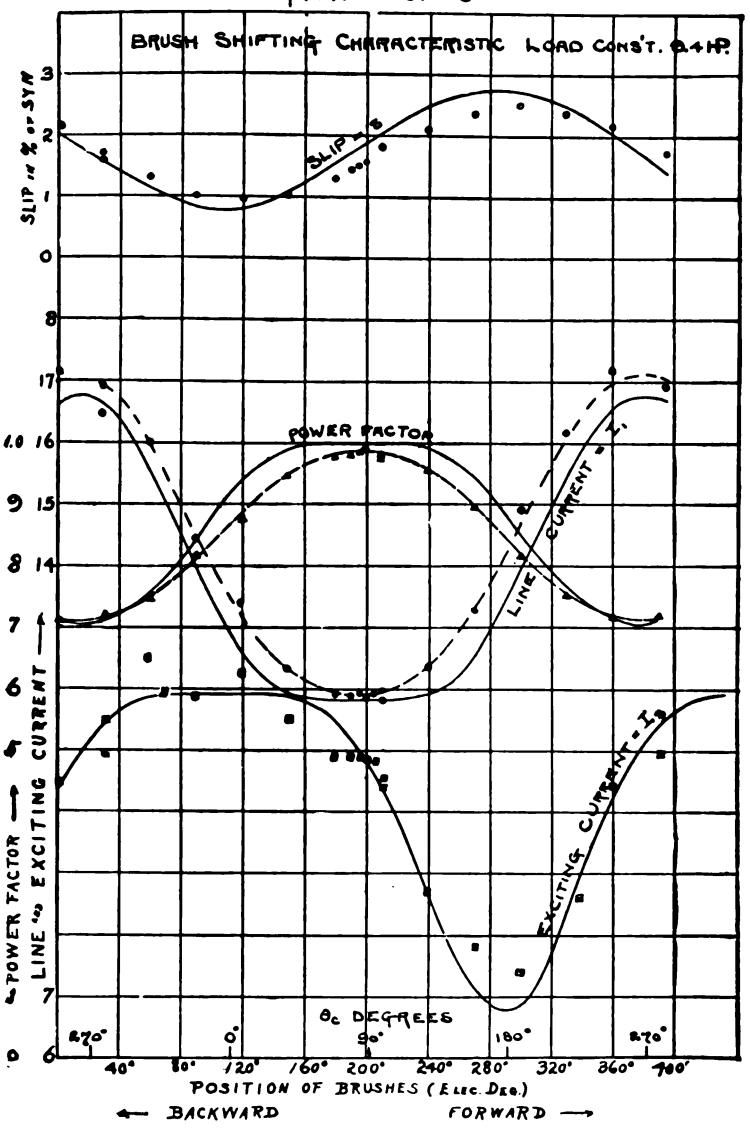
FIG. 16.
CONSTRUCTION DIAGRAM FOR BRUSH-SHIFTING CHARACTERISTICS AT NO LOAD.

It is to be expected that most of these induced harmonics will appear in the squirrel cage, but there will still remain in this case about one-fourth for the primary, which is sufficient to bring about a very material reduction of the power factor at no load when the primary energy is small.

The writer much regrets an accident to the oscillograph while preparing to test the validity of this theory, although there can be little doubt that this disturbance is quite appreciable at light loads.

As the energy current increases, the harmonics dwindle by comparison, so that at full load neither of the above mentioned disturbances are likely to introduce any considerable error.

FIG. 14. TEST #3


BRUSH SHIFTING CHARACTERISTIC LOAD CONST. 0.4 HP.
SLIP IN % OF SYN
SLIP
POWER FACTOR
LINE CURRENT = I
EXCITING CURRENT = Ie
POWER FACTOR → LINE & EXCITING CURRENT
θc DEGREES
-270° 0° 90° 180° 270°
40° 80° 120° 160° 200° 240° 280° 320° 360° 400°
POSITION OF BRUSHES (Elec. Deg.)
← BACKWARD FORWARD →

The same phenomenon is very prominent in a synchronous motor at light load; the shape of the induced e.m.f. wave is not the same as that of the impressed wave. It has been shown by

Rosenberg[1] that when current and e.m.f. are in phase, the power factor of a synchronous motor at no load is sometimes as low as .4.

The difference between the observed and calculated power factor and current, thus explained, appears in all the light load observations, sometimes more, sometimes less prominent, according to the amplitude of surging and the magnitude of the exciting current.

Test No. 3, *Fig.* 14.—This test was similar to No. 2, except that the motor was loaded to about its normal capacity. The exciting current I_e was a little greater than in Test No. 2.

As in No. 2, the solid curves show the results of an approximate calculation and the points and broken curves the results of ob-

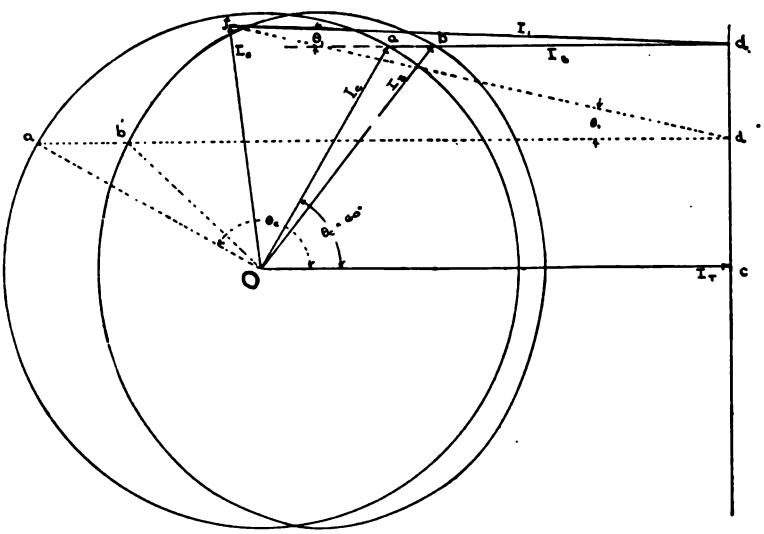


FIG. 15.
CONSTRUCTION DIAGRAM FOR BRUSH SHIFTING CHARACTERISTICS AT FULL LOAD.

servation. The approximate diagram drawn to scale is given in Fig. 15, in which the variation of the several quantities can be easily traced.

The slip being much greater, the slip current in the exciting winding, and therefore the variation in I_3 will be greater. The slip never reaches zero in this case, since the exciting current is not large enough to relieve the secondary entirely of its large torque current, even when the former is in phase with the latter.

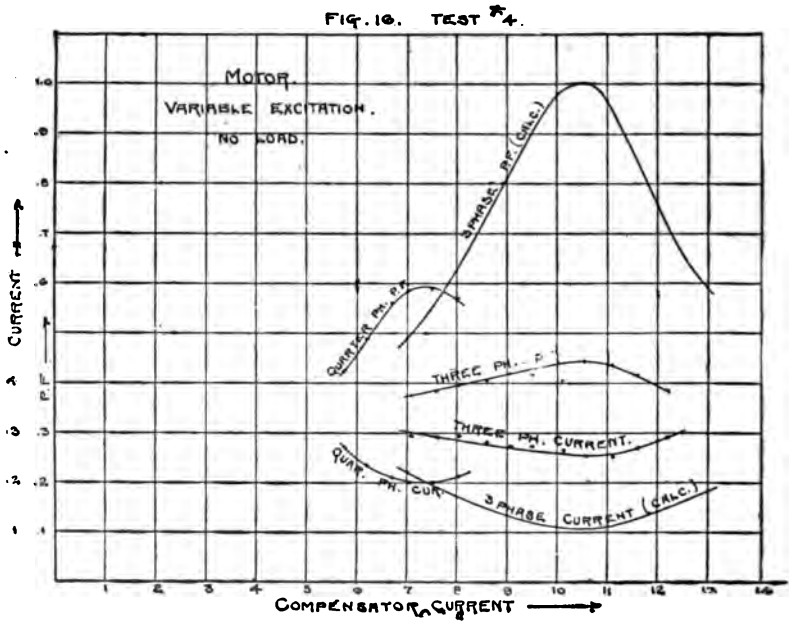
1. *E. T. Z.*, Feb. 12, 1903.

The discrepancy between the calculated and observed power factor and current is not nearly so great as in the no load case, for reasons already given, and the apparent discrepancy is due partly to the neglect of leakage in the calculations.

Test No. 4, *Fig.* 16.—In this case the brushes were left stationary throughout, in the magnetizing or quadrature position, determined by the preceding tests. The machine was running light, and the excitation was varied over a wide range. The line current and p.f. alone were plotted. These tests were made, one with 3-phase and the other with quarter-phase excitation.

Power factor and current curves were calculated for the three-phase case and are shown in the figure.

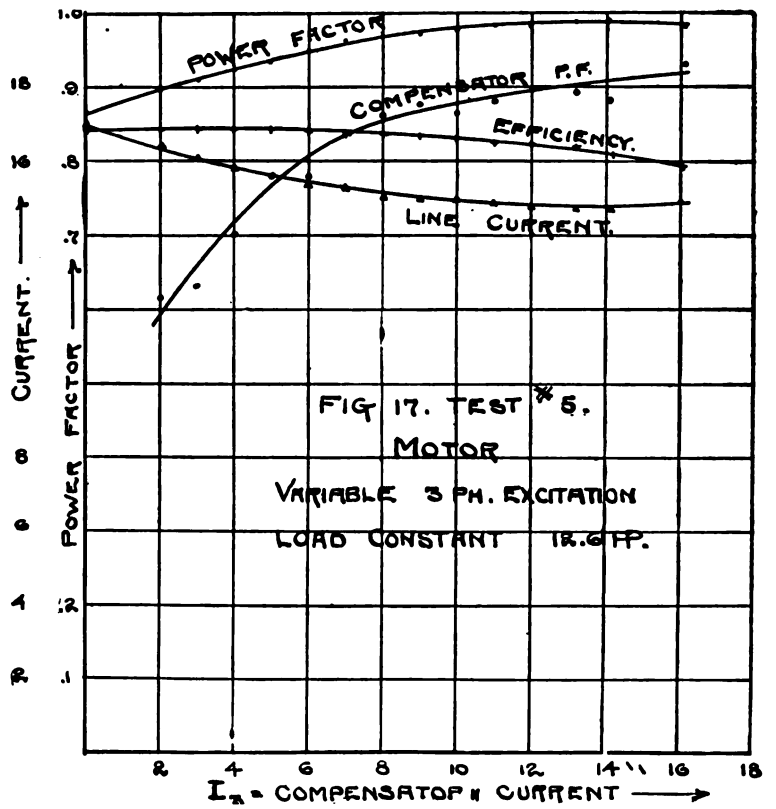
FIG. 16. TEST #4.



Comparison of the observed and calculated results shows very clearly the marked effect of the surging and of the wattless harmonics in the primary. That the latter were present in this case is quite certain on two accounts: first, the lowest point reached by the ammeter needles in their swing was not low enough to correspond to a unit power factor; secondly, because the quarter phase excitation gave a considerably higher p.f. than the three phase. This is just what would be expected, since the m.m.f. harmonics are much less prominent in the quarter-phase four-belt winding.

Had these two tests been made on different days the above conclusion would hardly be warranted, as the degree of surging differed so much from day to day; but they were made at the same sitting, and there was no appearance of change in any of the conditions.

Test No. 5. Fig. 17.—This was similar to the preceding, except that the machine was heavily loaded. Three-phase excitation alone was used, and the brushes were kept in the magnetizing position.

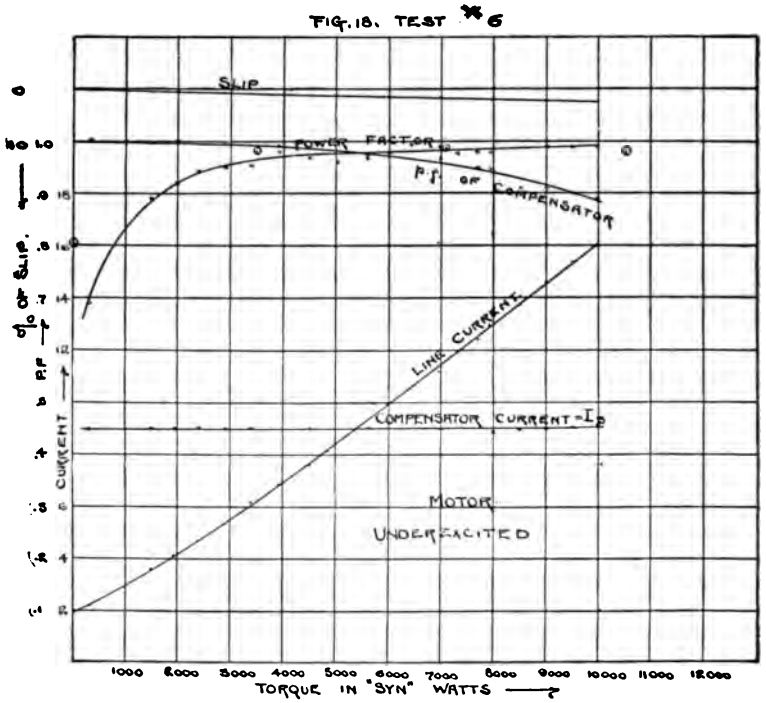


The power factor does not quite reach unity, showing even here a perceptible error due to the surging. It is not likely that the wattless harmonics have any appreciable effect upon the power factor in this case, when it is remembered that a power factor of 99 corresponds to a wattless component of .14, which would here be more than two amperes.

The *efficiency* curve in Fig. 17 shows that the copper loss in

the exciting winding more than balances the saving in primary copper loss, but this is also evident from a contemplation of the relative resistances of the two windings.

The curve marked " compensator power factor," shows the p.f. of the current delivered to the exciting winding, and would be approximately unity were it not for that part of the slip current which flows in this circuit. This slip current is approximately constant in this case, and in quadrature with the exciting current proper. Thus, as the latter increases, the power factor will increase, as shown by the curve.

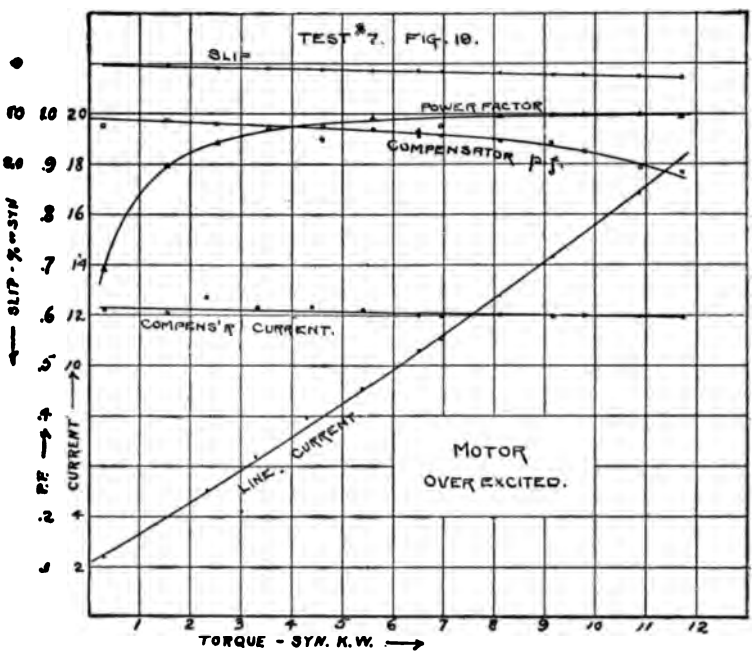


The power factor thus gives approximately the ratio between the real exciting current I_c and the total compensator current I_3; and since the curves of Fig. 17 are plotted against I_3, the latter must be multiplied by the compensator power factor, in order to give the real exciting current.

A comparison of this with the calculated excitation characteristic of Fig. 8 will show a good agreement as to the exciting current necessary to produce the maximum power factor at this particular load

Test No. 6, *Fig.* 18.—Exciting voltage and brush position both constant, load varied. As the excitation is low the power factor never reaches unity. The four points in large circles were calculated, and show that except at light loads the discrepancy is small. This is also true of test No. 7. In both of these cases there was much less surging at heavy loads than in most of the other tests.

The slip is less than in the uncompensated test, No. 1, owing to the added conductivity of the exciting circuit closed through the brushes.



The compensator current remains practically constant despite the increase of its slip component as the load increases. This means that the exciting current I_c decreases, due to the heating of the exciting winding

The compensator power-factor is interesting, as it shows what has been demonstrated theoretically above, that near synchronism the reactance of the exciting winding is negligible. It also shows the decrease of the power factor due to the increase of the slip current in quadrature with the exciting e.m.f.

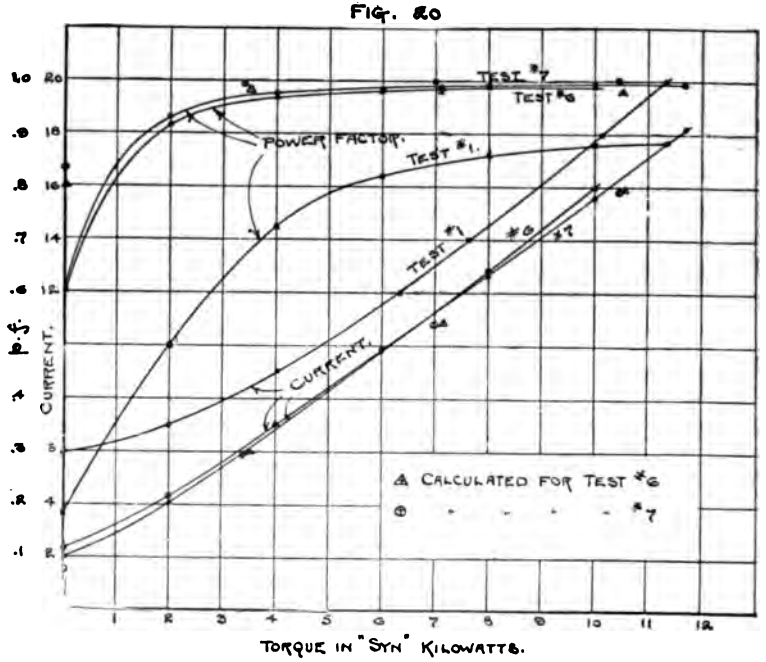
Test No. 7, *Fig.* 19.—In this test the motor was overexcited. The primary current leads at light loads, the power factor grad-

ually rising to unity and dropping a very little at the end. The calculated power factor points are shown again in large circles.

Owing to the larger exciting current, the winding heats more than in test No. 6, and the resulting decrease in exciting current more than balances the increasing slip current; thus I_s decreases slightly with load.

For clearness in comparison, the current and power factor curves of tests numbers 1, 6, and 7 are plotted together in Fig. 20. A glance at the calculated power factor points of Fig. 20 will show that it is quite possible to maintain the power factor of such a

FIG. 20



motor very nearly at unity, throughout its whole working range, by means of a constant exciting voltage. But it should be remembered that very nearly unity is not unity, and that a deviation of 1 per cent. therefrom means 14 per cent. of wattless current, about one-third as much as with a 90 per cent. power factor. In other words, a compensated motor may have a beautiful appearing power factor curve and still absorb a considerable wattless current. This is probably what lead Mr. Heyland to say that a constant exciting current would give perfect compensation at all loads.

There is thus no question as to the calculation or operation of this type of motor, the power factor is entirely within control and it can undoubtedly be made to operate sparklessly, but the question is, will it pay to sacrifice the beautiful simplicity of the ordinary induction motor for a little saving of wattless current, for there is no gain in other directions, either in efficiency or in starting torque. These are the directions in which the consumer is interested; he does not care much about the power factor.

There will of course be time and places where the power factor is a sufficiently vital question to warrant the use of the compensated commutator motor, but it is the writer's opinion that the Heyland machine as motor will not find a large field of usefulness in this country.

The Heyland Machine as Generator.

If a simple induction machine while operating as motor in connection with a network, be connected mechanically to a prime

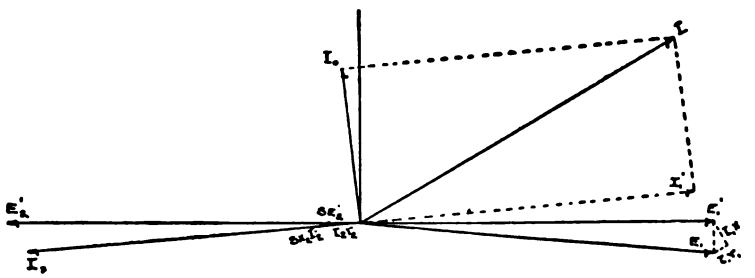


Fig. 21
Simple Induction Generator

mover and driven above synchronism, the slip and slip-current will reverse, as will the energy component of the primary current. The machine will then be operating as generator, but with leading current (see Fig. 21). The amount of this lead depends upon the same factors upon which depends the lag in the induction motor, namely: the exciting current and the leakage. Such a machine can never be connected to a dead load but must be used where the wattless magnetizing current can be supplied by some synchronous machine connected with the system.

If now the machine in question be supplied with a magnetizing current through a separate winding and commutator, as above described, the lead of the primary current may be reduced in any

desired amount (see Fig. 22), where the current is brought into phase with the terminal e.m.f. Assume that while thus operating without phase displacement the machine could be suddenly transferred from the network to a dead load of exactly the same magnitude (the exciting winding or the primary of its transformer being still connected to the machine terminals), it will continue to carry the load without change of voltage and will be a self-exciting shunt alternator. If now the external load resistance be decreased, the resulting increase of current will cause a larger drop, and the decrease in terminal e.m.f. will react upon itself through the excitation and flux, in a cycle very similar to that of the direct current shunt machine.

The end of this cycle for any given change of load resistance, depends upon the saturation curve as in the similar direct current

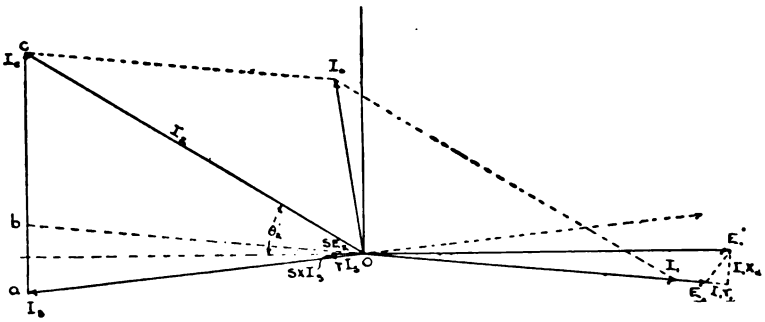


FIG. 22.
HEYLAND MACHINE AS GENERATOR

machine, but there is this difference: in the latter case that part of the drop due to armature reaction is dependent upon the brush position as well as upon the magnitude of the current, whereas in the machine under consideration the energy component of the armature reaction is balanced by the slip current, leaving a wattless demagnetizing component whose magnitude, in the case of a non-inductive load, depends upon the magnitude of the primary current and of the leakage reactance of both primary and secondary. This is best understood by a consideration of the diagram Fig. 22, where $\bar{o}\,\bar{b}$ is a continuation of I_1 backwards.

In the case of an inductive load there is the additional quadrature component due to the reactance of the load. Then $\bar{b}\bar{c}$ is approximately equal to the magnetizing component of I_0, which in turn is dependent upon E'_1. The total magnetizing current,

I_c, may then be considered as made up of two parts, $\bar{bc}$ consumed by the reluctance of the magnetic circuit, and $\bar{ab}$ required to balance the demagnetizing components of I_1 and I_s. These demagnetizing components are, in the case of a non-inductive load due to the leakage reactance in primary and secondary; but in the case of inductive load there is the additional wattless component due to the load itself. The lagging load has the additional effect of causing a greater drop between the internal e.m.f., E'_1, and the terminal e.m.f., E_1, as in the case of any alternating current generator.

In order to simplify the problem the demagnetising component of the armature reaction may be reduced to an equivalent armature reactance. Then the exciting current I_c may be considered as acting alone to produce a corresponding flux in the magnetic circuit and a corresponding e.m.f. in the primary, the relation between the exciting current and this e.m.f. being given by the saturation curve. Of this total induced e.m.f., E_0, a portion is consumed by the fictitious or apparent impedance of the armature, which impedance evidently depends upon the power factor of the load as well as upon the constants of the machine.

We then have in the shunt machine driven at constant speed,

E_0 dependent upon I_c as shown by saturation curve.

E_1 less than E_0 by the drop due to the apparent impedance.

I_c proportional to E_1.

For every value of I_c there will be a corresponding total e.m.f. E_0 generated, and a corresponding terminal e.m.f., E_1, required to produce the exciting current in question, the difference between E_0 and E_1 being available for impedance drop, to which the current will be roughly proportional. With an inductive load the apparent impedance will be greatly increased and the corresponding current much less.

If however the E_0 generated by any particular I_c is less than the E_1 required to produce that value of I_c, it is evident that the machine will not operate at that point, even at no load.

These relations are shown more clearly in Fig. 23. The curve marked E_0 is the open circuit e.m.f. of the machine tested, plotted against the exciting current reduced to primary turns by the ratio 1.68 which, it will be observed, differs from the constant 1.79 worked out on the assumption of sinusoidal flux distribution. The constant, 1.68, was experimentally determined by comparing the saturation curves obtained from the machine as motor, and as generator on open circuit, both at 60 cycles.

The points marked with a circle were obtained by the former and those with a triangle by the latter method. The generator points were assembled from the no-load readings of a number of tests taken at different times and with slightly different brush positions.

The straight line, $N_{2c} = 24$, has for its tangent the resistance of the exciting winding reduced to primary turns and to primary volts, when 24 turns on the secondary of the compensator were in use. A similar description applies to the other straight lines.

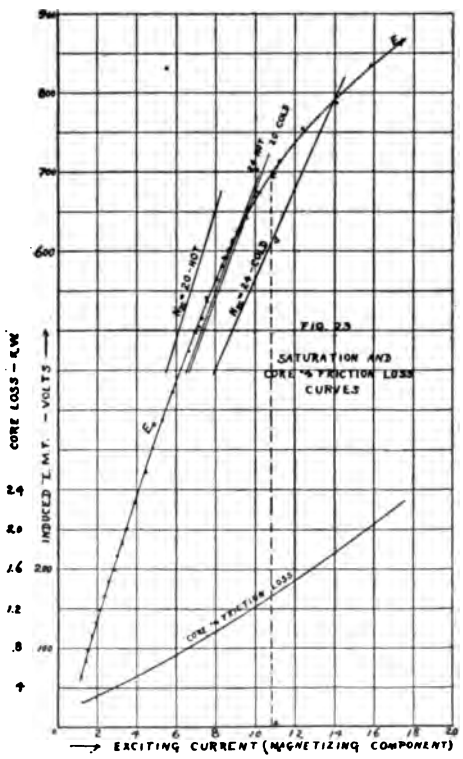


FIG. 23
SATURATION AND CORE & FRICTION LOSS CURVES
CORE LOSS - K.W.
INDUCED E.M.F. - VOLTS
EXCITING CURRENT (MAGNETIZING COMPONENT)

The intersection of any one of these straight lines with the saturation curve gives the no-load e.m.f. corresponding to the exciting conditions represented by that line. The hot and cold resistance lines are given to show the great difference in terminal volts due to a change of temperature of the exciting winding.

For any given current the terminal volts will drop from the no-load value along the resistance line to a point b such that the vertical intercept $\bar{bc}$ is the impedance drop due to the given cur-

rent. The maximum current which the machine can carry for any given number of turns on the secondary of the compensator is thus determined by the maximum intercept $\bar{bc}$, between the corresponding resistance line and the saturation curve. As the p.f. of the load decreases, the apparent impedance increases very rapidly, and the corresponding maximum current decreases accordingly.

It is thus apparent that stable operation as a shunt machine cannot be secured below 600 volts, even for a small armature current, owing to the low densities in the magnetic circuit at normal pressures. The maximum densities in maxwell's per square inch at the normal e.m.f. of 440 volts, are approximately as follows:

E_1	440	800
Stator Core	32800	59700
Stator Teeth	49000	89000
Rotor Core	66200	120300
Rotor Teeth	49000	89000

At 800 volts, which is practically about the lowest safe running point as a shunt machine, the densities would be as given in the second column. The corresponding core loss is excessive as shown by the curve of Fig. 23, the natural remedy being a reduction of the rotor core section to such a point that the maximum rotor core density would be about 130000 at normal voltage.

The excessive pressures thus required in the generator tests were very troublesome in several respects. The correspondingly large exciting currents caused excessive heating of the exciting winding and made it practically impossible to get a complete set of readings without serious change in the resistance of this winding. The vicious sparking which accompanied the large exciting currents caused constant trouble at the commutator and such a wearing back of the brushes that, during a test of a couple of hours, they changed their location ten or fifteen electrical degrees. The condition of the commutator also affected the resistance of the exciting circuit.

Under these circumstances it can be readily understood why it was impossible to duplicate the conditions of any given test or to maintain the same conditions long enough to get a consistent set of results.

Fig. 24 shows four shunt characteristics the results of tests numbers 9, 10, 11 and 12. In each case the load was pushed to

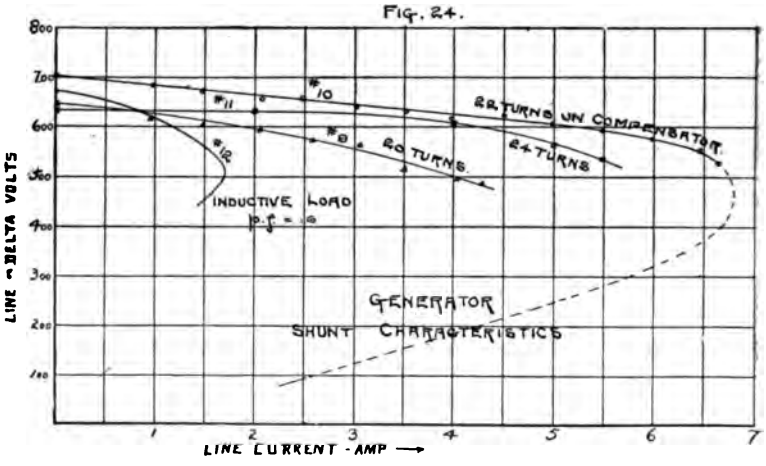
the unbuilding point which was considerably inside the current capacity of the machine.

In tests numbers 9 and 10, the machine was comparatively cold at the start and the droop of the characteristics is partly due to the heating of the exciting winding.

In test No. 11 the exciting winding was allowed to heat up before taking the readings, and the result is very apparent, for although 24 turns of compensator secondary were in use, the no-load voltage was lower than in the case of No. 9 with only 20 turns.

In No. 12 the power factor was about .6, and the machine started warm with 24 turns on the compensator secondary.

FIG. 24.



In each case the brushes were set in the magnetizing position, which is the same for motor and generator.

The slip was measured in one or two instances and found to agree entirely with the calculations, about .11 per cent. per ampere of energy current at 600 volts.

In all of these tests the machine was very unstable, and very sensitive to speed and to brush position, as might have been predicted from the saturation curve.

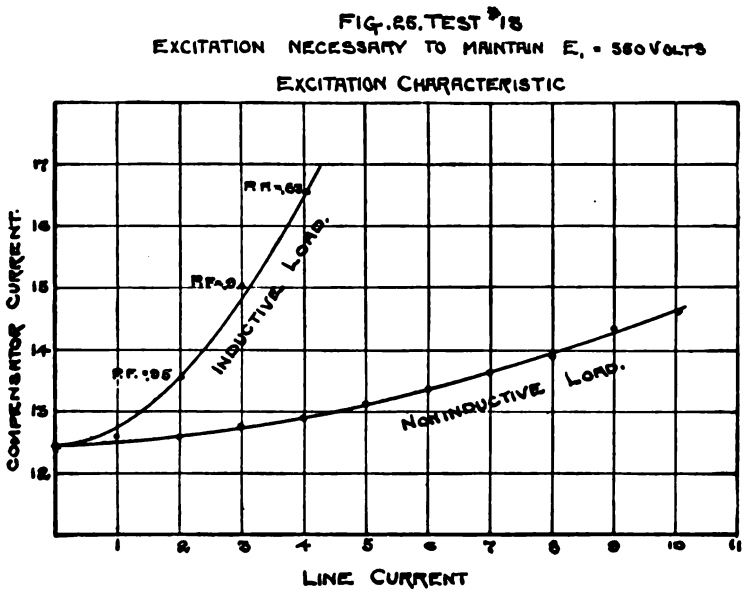
Compound Excitation.

Of the two parts into which we have divided the excitation, that part consumed by reluctance $\bar{b}\,\bar{c}$, Fig. 22, is dependent upon the total induced e.m.f. E'_1, of the primary, and is therefore required to increase only slightly with increase of load and con-

stant terminal e.m.f. The remaining portion, $\bar{a}\,\bar{b}$, due to the leakage, increases approximately as the square of the current, under non-inductive load.

Thus for moderately small non-inductive loads the demand for increased excitation is so small that a shunt machine will maintain an almost constant terminal e.m.f. over a moderate range. This is shown in Shunt Characteristic No. 11, Fig. 24, where the temperature of the exciting winding was constant. The smaller the leakage the farther out will the characteristics hold up.

This was probably what lead Mr. Heyland to say that the



shunt excitation gave perfect compensation with non-inductive load.

The excitation required for the complete compensation of this particular machine is shown in Fig. 25. The upper curve shows clearly the large increase made necessary by the reaction of the quadrature component of the lagging load current.

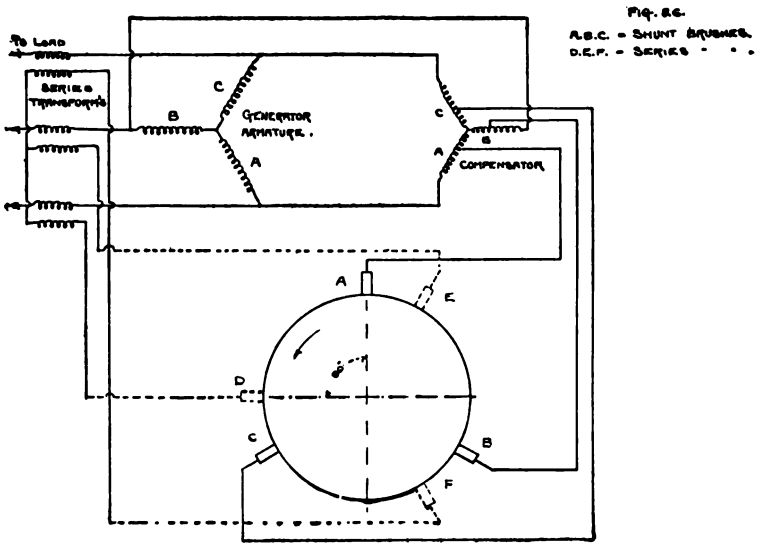
Hence the requirements for compounding are much as in the case of a synchronous alternator, except that owing to the relatively small reluctance m.m.f. in the induction generator, the percentage increase for inductive loads is considerably greater.

There are two distinctly different methods of compounding, one

in which the shunt exciting current above considered is increased by some arrangement of compounding transformers, and the other in which the shunt excitation is left as in the simple shunt machine, and the armature reaction completely balanced by sending the armature current, or some fixed proportion of it, into the exciting winding through a separate set of brushes about 90° from the shunt brushes.

The last mentioned arrangement is the one used by Mr. Heyland and is shown in Fig. 26.

Assuming that the ratio of transformation of the series transformer is such as to produce an m.m.f. in the secondary a little



larger than that of the primary, and that the brushes are so set that its space phase is exactly opposite to that of the primary, the slip-current will be supplanted, and together with the slip, will disappear, leaving a practically synchronous machine. The only function of the shunt excitation is then to supply the reluctance m.m.f. which is nearly constant. The slight increase in the latter, necessary to maintain constant terminal e.m.f., may be obtained by shifting the series brushes backwards a very little in order to throw a small component of the series excitation into the magnetizing phase. The result is perfect compounding for all power factors, as illustrated in Fig. 27, where the vector sum

of the shunt and series exciting currents is designated I_2, the total secondary current, and where the vector sum of I_1 and I_2 is a magnetizing current I_0, which increases slightly with the load.

The last paragraph is a statement of the theory of the method as ordinarily propounded, and assumes that the presence of the series current will not disturb the shunt current. With the arrangement employed in the tests here recorded, this assumption is not warranted.

This will be best appreciated by reference to Fig. 26, where A, B and C are the shunt brushes connected as indicated, and set in the magnetizing position, *i.e.*, in a position such that when the currents entering these brushes are in phase with their respective e.m.f's.,these currents will supply an m.m.f. 90° in advance of the terminal e.m.f.

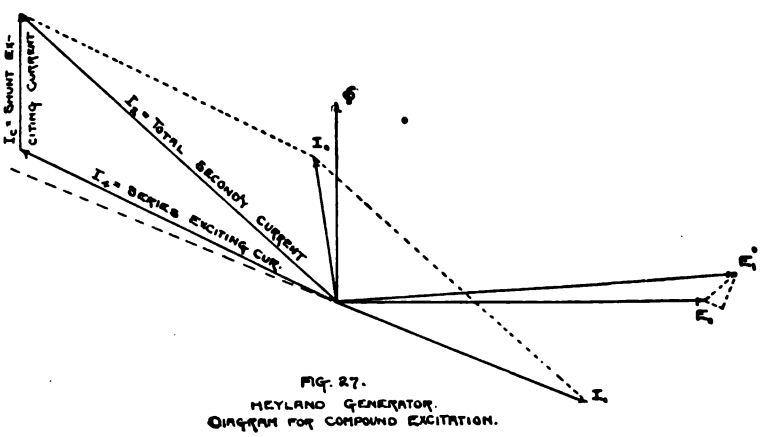


FIG. 27.
HEYLAND GENERATOR.
DIAGRAM FOR COMPOUND EXCITATION.

If the load is non-inductive and the series transformers connected to the series brushes D, E and F, as shown, the current entering the brush D will be of the same time-phase as the potential of brush A. In order therefore to place the m.m.f. of the series current in opposition to that of the primary current the series brushes must be placed approximately 90° in advance of the shunt brushes, as shown. But this places D, E and F only 30° behind C, A and B respectively, and since the potentials of the latter are fixed, it is evident from the proximity of the two sets that there will be a tendency on the part of C, A and B to control the potentials of D, E and F, and that the nearer the two sets the greater will be the degree of control.

The tendency of this control is to restrict the resultant current

to that which would flow under the action of the shunt e.m.f. alone, or since the series current is fixed in phase and magnitude, the shunt current will tend towards a value such that the resultant current will be as above described.

It has been explained above that in order to give the series m.m.f. a slight magnetizing component the series brushes should be shifted slightly backwards from the 90° position shown in Fig. 26; this would separate the two sets of brushes and make the two excitations more independent.

In the tests under consideration the following arrangement was used. The connections between the secondaries of the series transformers and the series brushes were reversed from those shown in Fig. 26, the other ends of the secondaries being con-

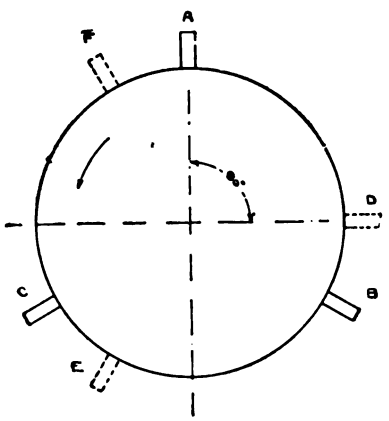


FIG. 28.

nected to the star and the ends shown in star connection carried to the brushes. This made it necessary to shift the series brushes 180° to the position shown in Fig. 28, so that the slight additional backward shift brought them closer to the shunt brushes, instead of separating them further as in the Fig. 26.

As the two sets of brushes were separated by a considerable angle (measured in mechanical degrees), the machine having six poles, the electrical proximity was not appreciated at the time of the tests.

It was found necessary in order to hold up the terminal e.m.f. under load, to give the series brushes an extra backward shift of from 25° to 50°, which would bring the two sets of brushes into practical coincidence on the two pole diagram, but always separ-

ated by an appreciable resistance in the actual machine, which had a six pole series closed coil winding.

The conditions were therefore such as to minimize the compounding effect of the series excitation. The appreciation of these conditions will assist materially in the interpretation of the experimental results.

Test No. 14, *Fig.* 29.—Load non-inductive. No series transformers were used, the series brushes being connected to the inner

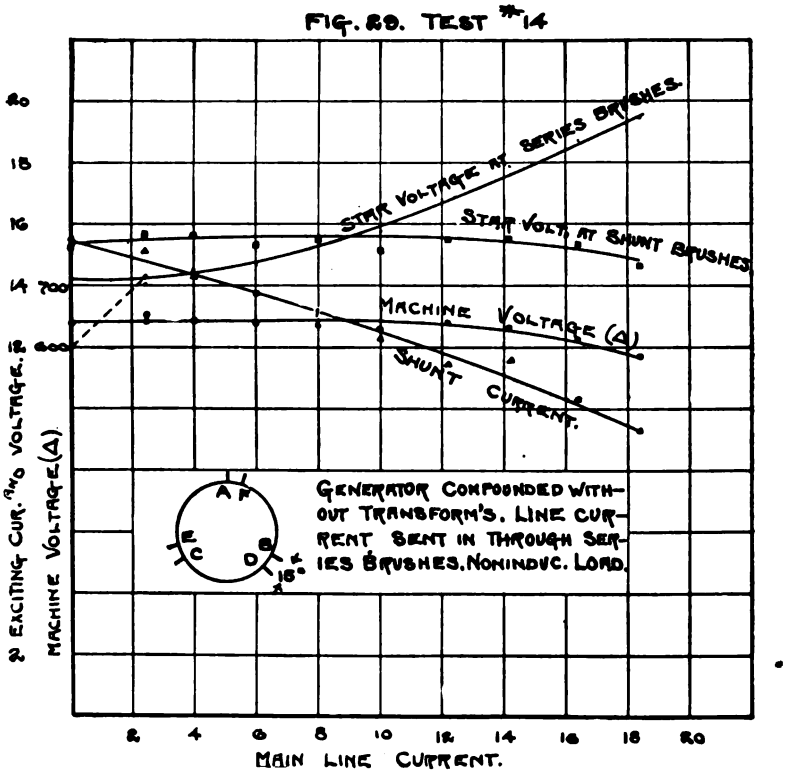


FIG. 29. TEST № 14
STAR VOLTAGE AT SERIES BRUSHES.
STAR VOLTS AT SHUNT BRUSHES.
MACHINE VOLTAGE (Δ)
SHUNT CURRENT.
GENERATOR COMPOUNDED WITHOUT TRANSFORM'S. LINE CURRENT SENT IN THROUGH SERIES BRUSHES. NONINDUC. LOAD.
A F E B C D 15°
MACHINE VOLTAGE (Δ)
MAIN LINE CURRENT.

ends of the machine star. The series brushes were placed 45° back of the slip position and 15° back of the shunt brushes, so that about 71 per cent. of the series current was thrown into the magnetizing position, but the resultant magnetizing current was nevertheless kept down by the proximity of the shunt brushes. Although thus restrained the compounding was sufficient to maintain a practically constant terminal e.m.f. up to the full load of 14 amperes.

A glance at the series and shunt e.m.f. curves will show the influence of the latter upon the former.

The phase relations of the several currents will be best appreciated with the aid of Fig. 30, in which are plotted to scale the current diagrams for three points of test No. 14. $\bar{of} = I_0$, the exciting current; $\bar{df} = I_1$, the primary current; $\bar{oa} = I_{2s}$, the slip-current in the squirrel cage; $\bar{ab} = I_{3s}$, the slip-current in the exciting winding; $\bar{ac} = I_3$, the actual shunt current; $\bar{cd} = I_4$, the series current; and $\bar{ad} = I_e$, the combined current in the exciting winding, all reduced to primary turns.

E_1 was first plotted, then E'_1 determined by adding the primary impedance drop. With E'_1, I_0 was taken from the saturation and core-loss curves. To I_0, I_1 was added, or more exactly, subtracted. I_{2s} was calculated from the measured slip. I_4 was plotted in its proper phase, as determined by the position of the

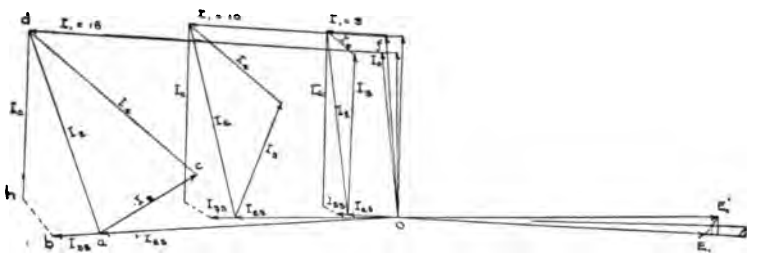


FIG 30
DIAGRAM FOR TEST 14 (DRAWN TO SCALE)

series brushes, and I_3 made to close the figure. The closing was somewhat forced, as was to be expected of the space composition of non-sinusoidal currents in a three-belt winding, reduced to a common basis by an uncertain reduction factor. The forcing however was not severe enough to lead to any doubts as to the general accuracy of the data.

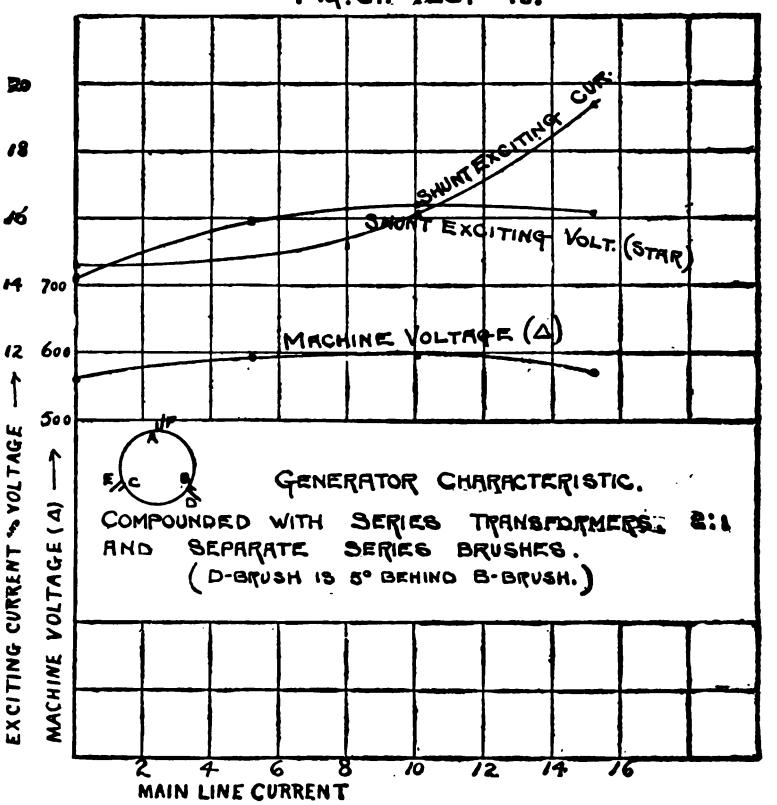
The vector $\bar{lu} = I_c$ represents the current that would flow in the exciting winding under the action of the shunt e.m.f. alone, the phase of I_c being determined by the brush position.

The total equivalent current in the exciting winding, I_e, may thus be considered as made up of a hypothetical shunt current I_c, dependent upon the shunt e.m.f., a slip-current $\bar{ab}$ and a current $\bar{bl}$ approximately in phase with and proportional to the series current, the constant of proportionality increasing with the electrical displacement between the two sets of brushes. When

the brushes of one set are just half way between those of the other, their currents should be practically independent of each other.

Test No. 15, *Fig.* 31.—Load, non-inductive. Series transformers, ratio, 2 to 1. D brush 5° behind B brush. The series current was thus twice as great as in test No. 14, but the greater proximity of the two sets of brushes reduced the proportion of the series current which was effective in compounding.

FIG. 31. TEST № 15.



At the end of this test an inductive load with a power factor of .9 was tried, and by shifting the series brushes farther back the machine was enabled to carry 3.5 amperes. This was the largest inductive load that was carried during any of the tests. With the arrangement shown in Figs. 26, and a proper transformation ratio, the compounding would be more satisfactory; but it is very doubtful if the machine would even then maintain its pressure with an inductive load and fixed brush position.

With single-phase compound excitation, the series and shunt brushes would be 90° apart; *i.e.*, the series brushes would be half way between the shunt brushes, where the series current would least disturb the shunt current. This accounts for the fact noted by Mr. Heyland, that single-phase excitation was more satisfactory than three-phase excitation.

With quarter-phase excitation the series and shunt brushes would be practically coincident, and compounding for inductive loads impossible.

If a separate winding and commutator were provided for the series excitation, as described by M. Latour, the above described difficulty would not be experienced.

Doubtless better results could have been obtained with the arrangement used, if higher shunt excitation had been employed

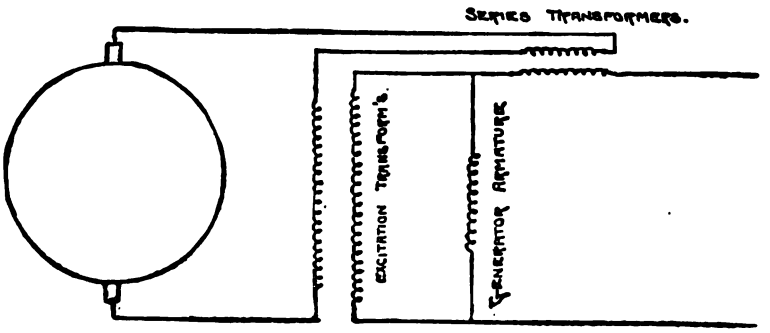


FIG. 32.

so as to render the machine inherently more stable. This type of machine however is illy adapted to the ideal compounding illustrated in Fig. 27, since then the small exciting winding would be forced to carry the total secondary current, and the squirrel cage would serve no purpose except to carry the remnant.

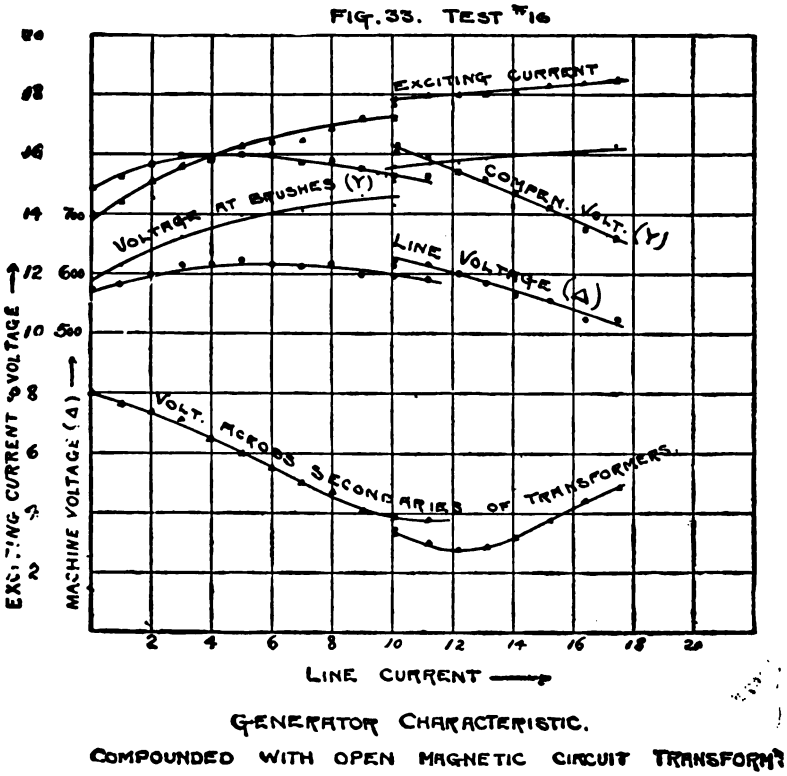
The other method of compounding, in which the shunt exciting e.m.f. is increased by an amount depending upon the phase and magnitude of the load, is much better suited to this particular machine.

Several more or less complicated arrangements are available, but the only one used in these tests is that shown in Fig. 32, its chief recommendation being its simplicity.

An open magnetic circuit transformer is inserted into each of the machine phases and its secondary connected in series with the

corresponding exciting phase. In order to avoid unnecessary complication, a single-phase machine is shown in the diagram.

The transformer introduces into the exciting circuit an approximately quadrature e.m.f. of magnitude proportional to the resultant of primary and secondary ampere-turns. At no load this quadrature component is in advance of the exciting current and is relatively large. As the load on the alternator increases, the reactive e.m.f. decreases and finally reverses; meanwhile the



effective e.m.f. at the brushes, and therefore the exciting current, increases steadily and also advances in phase.

The above assumes a non-inductive load; if however the load be inductive, the quadrature component of the load current will induce an e.m.f. in the secondary of the transformer which will be almost in phase with the exciting current.

Such transformers could be easily designed to compound for any given power factor, but would over-compound for higher and under-compound for lower power factors, assuming an induction

machine of ordinary proportions. If the machine had a long air gap, so that the percentage increase in excitation for inductive load were not so great, a fair compromise might be made for all power factors.

One of the drawbacks of this arrangement is that with fixed brush position the advance of the phase of the exciting current

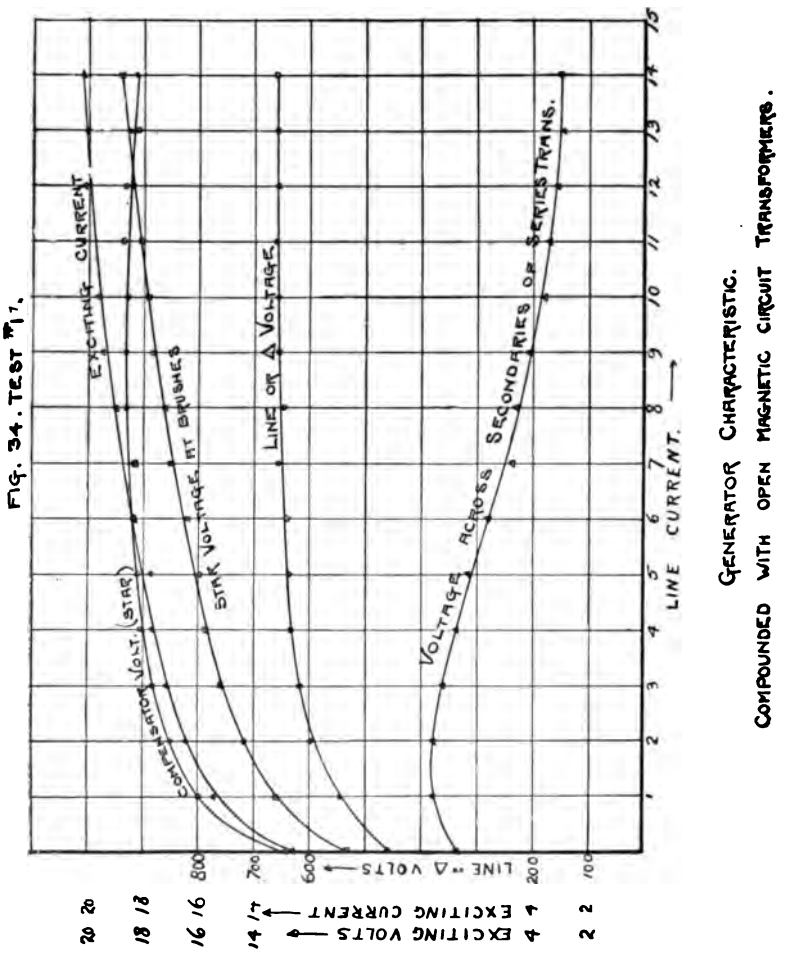


FIG. 34. TEST No 11.

causes an increase or decrease of its effectiveness according as the brushes were initially too far back or forward.

If set at the best full load position the no load e.m.f. will be low and vice versa. These points are shown clearly in the two non-inductive load characteristics of Figs. 33 and 34.

In the former case the brushes were set in advance in the best light load position and shifted backwards 15° for the last section of the curve.

In test No. 17 of Fig. 34 the brushes were set at the start in the best full load position, *i.e.*, in the same position as for motor or shunt generator operation.

The other curves are what were to be expected, the e.m.f. of the series transformer decreases to a minimum and then reverses sign.

A small inductive load was all that the machine could carry with this method of compounding, for reasons already given.

A machine compounded by the first described method operates practically at synchronism, whereas in the last described type of excitation only the magnetizing component is supplied from without, the slip current remaining unchanged. The frequency will therefore decrease with load, constant driving speed assumed.

Several of the questions which developed during the working up of these tests, answers to which have been here given by deduction, would have been answered by experiment had the machine not been previously returned to the General Electric Company to be remodelled.

It would be obviously unfair to judge the Heyland machine by the fact of the above-described tests, but granting all that Mr. Heyland claims, the chief advantages of this type of alternator are, briefly:

Non-synchronous, ease of paralleling;
Automatic compounding for all power factors.
Short air gap, small exciting power;
No exciter required;
Economy of material;

and the disadvantages:

Commutator, this is prohibitive in low speed machines;
More complicated;
Much greater first cost per lb. of material;
Natural ventilation poor.

The automatic compounding is of little value in a large central station, and the exciting power cannot well be reduced below that of good synchronous machines.

The higher price of materials and lower price of labor in Europe may make a success there out of what would be very doubtful here.

The Heyland generator is naturally, for commutator reasons, a high speed machine with a small number of poles, and may

prove useful in connection with steam turbines, although the high commutator velocity may be troublesome.

In conclusion the writer wishes to thank the General Electric Company for the opportunity of making the tests above recorded, and to express his appreciation of the valuable assistance rendered by Messrs. Anderegg, Whiting, Snyder, Trowbridge, Burchenal and Willis, in connection with the taking of observations and the working up of the results, and by Prof. Kennelly in the final preparation of this paper.

BIBLIOGRAPHY.

Görges, *Elektrotechnische Zeitschrift*, December 25, 1891.
Blondel, *L'Eclairage Electrique*, August 29, 1896.
Heyland, *Elektrotechnische Zeitschrift*, August 8, 1901.
Leblanc, *L'Eclairage Electrique*, October 26, 1901.
Heyland, *Elektrotechnische Zeitschrift*, November 7, 1901.
Latour, *L'Eclairage Electrique*, November 30, 1901.
Heyland, *Electrotechnische Zeitschrift*, December 12, 1901.
Heyland, *Electrotechnische Zeitschrift*, January 9, 1902.
Poincaire, *L'Eclairage Electrique*, Jaunary 18, 1902.
Latour, *Electrical World and Engineer*, February 1, 1902.
Latour, *L'Industrie Electrique*, February 25, 1902.
Heyland, *L'Eclairage Electrique*, March 22, 1902.
Latour, *L'Industrie Electrique*, April 10, 1902,
Latour, *L'Industrie Electrique*, April 25, 1902.
Latour, *L'Eclairage Electsique*, April 12, 1902.
Breslauer, *Zeit. fur Elek.*, April 20, 1902.
Picon, *L'Industrie Electrique*, May 10, 1902.
Boy de la Tour, *L'Industrie Electrique*, June 10, 1902.
Heyland, *Elektrotechnische Zeitschrift*, June 26, 1902.
Latour, *Elektrotechnische Zeitschrift*, July 3, 1902.
Heyland and others, *Bull. Soc. Int. des Elect.*, July, 1902.
Zeigenberg, *Elek. Anzeiger*, July 17, July 20, August 10, August 17, September 25, September 28, October 23, October 30. 1902.
Elek. Verein, Discussion, *Elektrotechnische Zeitschrift*, August 21, 1902.
Osnos, *Elektrotechnische Zeitschrift*, October 6, 1902.
Bragstadt, *Elektrotechnische Zeitschrift*, November 6, 1902.
Osnos and Breslauer, *Elektrotechnische Zeitschrift*, November 27, 1902.
Osnos, *Elektrotechnische Zeitschrift*, December 27, 1902.
Heyland, *Elektrotechnische Zeitschrift*, January 22–29, February 5, March 19, 1902.
Boy de la Tour, *Electrical World and Engineer*, March 14–21, 1902.
Since this paper was completed, the following have appeared:
Blondel, *L'Eclairage Electrique*, April 25, May 2. 1902.
Alexander and Fleischmann, *Zeit. fur Elek.*, May 10, 1902.

A paper read at the 177th Meeting of the American Institute of Electrical Engineers, New York, May 19, 1903.

THE COMPOUNDING OF SELF-EXCITED ALTERNATING CURRENT GENERATORS FOR VARIATION IN LOAD AND POWER FACTOR.

BY A. S. GARFIELD.

A description of the characteristics of a polyphase alternating current revolving-field generator provided with a single closed-circuit field-winding and commutator. Effect of shifting brushes at various inductive and non-inductive loads, represented graphically.

The present discussion refers to polyphase alternating current generators comprising a stationary armature and a revolving-field structure provided with a closed-circuit winding connected to a multi-segmental commutator.

A description of the characteristics of the generator provided with a single closed-circuit field-winding and commutator will probably facilitate an understanding of the compounded machine.

Fig. 1 represents a bipolar machine of the first type, comprising a delta-connected armature-winding T and a field structure with commutator R; the ohmic resistance of the closed-circuit field-winding being suitably designed with reference to the induced voltage at the armature-terminals in order to obtain the required ampere-turns in the excitation circuit.

The position of the commutator brushes relative to the armature-terminals is represented by the angle A o a, the frequency of currents induced in the armature by N and the constant angular speed of the field structure, R, by S.

If the machine is now run without load and with the brush position determined by

A o a $= \pi/2$ we will have N $=$ S
or A o a $< \pi/2$ we will have N $<$ S
or A o a $> \pi/2$ we will have N $>$ S

The most interesting brush position is that represented by $A\,o\,a = \pi/2$, the angular speed of the field structure then being equal to the frequency of the induced armature currents.

With the brushes in any position whatsoever, if the machine is loaded we have:

1. A diminution in frequency of the induced armature currents.
2. An increase of current in the closed-circuit winding of the field structure R.

Whenever load is removed with the brushes in any position whatsoever we have:

1. An increase in the frequency of the induced armature currents.

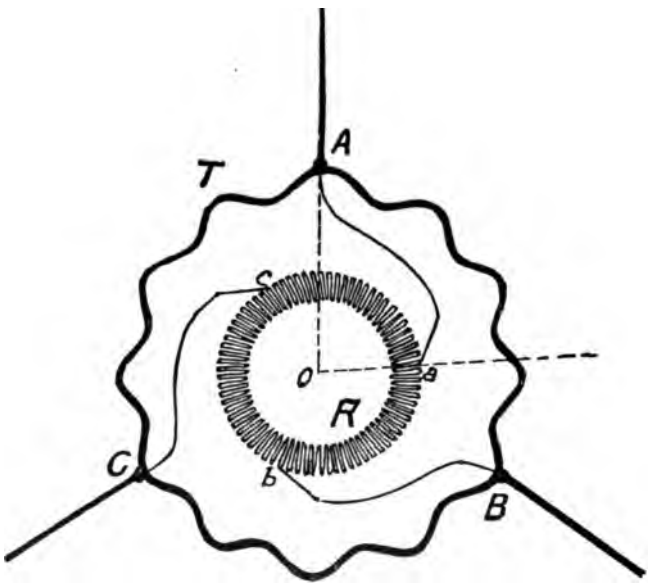


Fig 1.

2. A diminution of current in the closed-circuit winding of R.

With the brushes in any position whatsoever, that is, with $N < S$ or $N = S$ or, finally, $N > S$ and when the machine is without load we find, neglecting magnetic leakage, no armature reaction for induced currents with unit power-factor but the usual amount of reaction for wattless-currents.

If the brushes are moved:

1. In the direction of rotation, N increases.
2. In the opposite direction, N diminishes.

It is evident, therefore, that we can obtain for any load by a suitable change in position of the brushes:

$$N < S, N = S, N > S.$$

With the brushes in the position represented by $A\ o\ a = \pi/2$ at no load, we can always maintain $N = S$ by changing the brush position proportionally to the variations in load.

The following brush positions are interesting:

1. With the brushes placed so that $A\ o\ a = \pi/2$ for any load whatsoever, we will find $N = S$ at no load and $N < S$ when loaded. This is the characteristic operation of an induction generator.

2. The brushes may be set in a position corresponding to $A\ o\ a > \pi/2$, so that at no load we have $N > S$ and at full load $N = S$.

3. The brushes may evidently be set so that we have $N = S$ at any predetermined load.

In order to avoid the short-circuiting current in those sections of the field-winding connected to the commutator segments covered by the brushes, it is evidently necessary constantly to change the brush position in such a manner that N remains equal to S. If $N = S$ at no load, the same relation will be obtained with increase in load by moving the brushes forward in the direction of rotation of the revolving field. Under these conditions the frequency of currents induced in the armature will remain constant and the magnetic field fixed in position with reference to the inducing member.

In any event the variations in frequency will be of the same magnitude as the slip in well designed induction motors.

The graphical representation of these facts may be of interest. In Fig. 2, O R represents the ampere-turns of the field-winding, O T those of the armature and O F the resultant ampere-turns. $T\ O\ D = \varphi$, the phase-angle between current and e.m.f. The brush position $A\ o\ a$ corresponding to $N = S$, is represented by the angle D O R of Fig. 2. The magnitude of this angle evidently depends on the output of the machine and power-factor of the load, or, in other words, it varies proportionately to the inductive and to the non-inductive load on the machine.

Any variation in the inductive or non-inductive load will evidently leave the brushes in a defective position and if they were placed to give $N = S$ we will now have $N \lesseqgtr S$. In consequence of this an electromotive force proportionate to $N - S$ or $S - N$, as the case may be, will be induced in the field-circuit. When $N = S$ the impressed voltage $o\ a$ at brush terminals $a\ b$,

b c, or *c a*, which is the same as the induced voltage between terminals A B, B C or C A, counterbalances the ohmic drop O *e* in the field-circuits, including therein the drop in the brushes and brush-contact with the commutator. This ohmic drop is proportional to the ampere-turns O R of the field winding.

Referring now to Figs. 3 and 4 in which it is supposed that the brushes have a defective position A *o a* ≷ D *o* R, the impressed voltage O *d* at brush terminals will be represented in such a direction that D *o d* = A *o a* (either in advance of or behind the

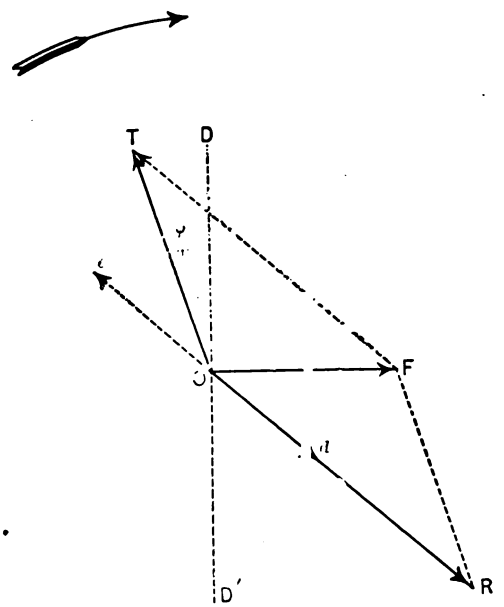


FIG. 2.

line O R.) This impressed voltage, O *d*, must be equal in magnitude and opposite in direction to the resultant, O *g*, of the ohmic drop, O *e*, in field winding, brushes and brush contacts and of the electromotive force, O *f*, induced in the field winding as a consequence of the modification of the relation N = S. If D *o d* < D *o* R, O *f*, representing the magnitude of the voltage induced in the field-winding must be laid off, as shown in Fig. 3, and the frequency of the currents induced in the armature will be diminished. With D *o d* > D *o* R,

o *f* must be represented as in Fig. 4 and the frequency of induced armature-currents will be increased. Any decrease in the inductive or non-inductive load on the machine corresponds therefore to an increase in frequency, and an increase in non-inductive or inductive load brings about a diminution of the frequency of the armature-currents. It is evidently possible to place the brushes in such positions as to ensure N = S at no load, half-load, full-load or overload, but in all cases the above-mentioned phenomena

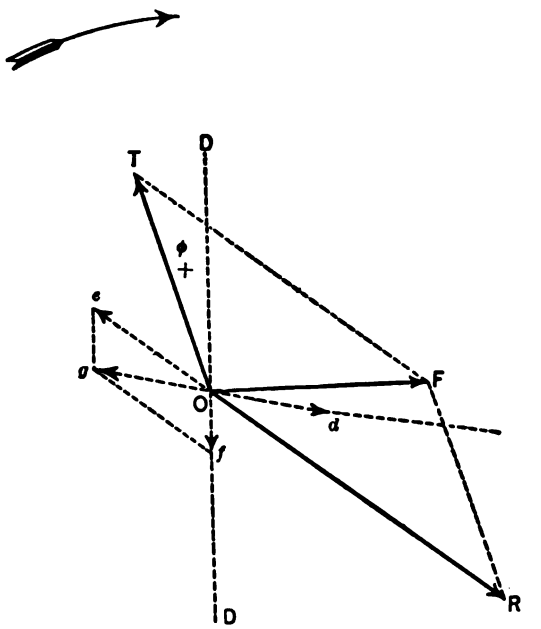


FIG. 3.

will be noted. Assuming the machine to work with a constant wattless output, and the brushes set for a certain load to give N = S, any variation in the load will result in the points *d*, and *g* of Figs. 3 and 4, remaining fixed in space, the points T and *e* being placed parallel to D D′, and the point *f* will be displaced along the line D D′. The machine will operate at constant terminal voltage but at variable frequency. The speed of rotation of the field structure has of course been assumed to be constant in the discussion.

Whenever a machine of the above description is connected to a network of given frequency, N, the brushes are set permanently in a fixed position, there is evidently a certain angular speed of rotation, N_1, of the machine, inferior, equal, or superior to the speed N which corresponds to the non-inductive no load output of the machine. The machine will take on load proportionally to the increase in speed above N_1, that is, to $N_2 - N_1$, where N_2 represents the speed of rotation of the machine when

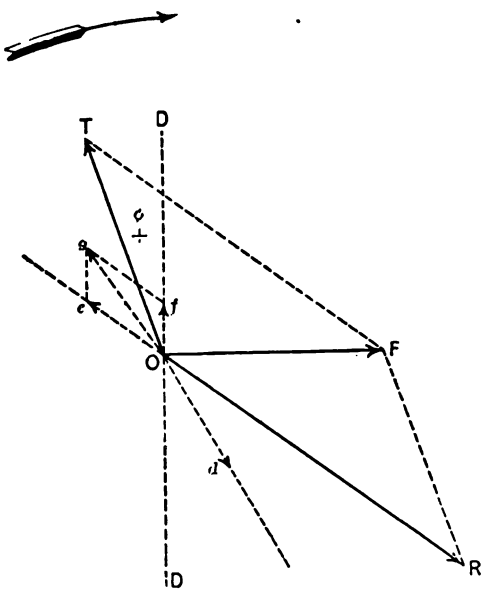


FIG. 4.

loaded. The wattless output of the machine will remain constant for all values of N_2. When it is zero, the machine operates with unity power-factor. The brushes would usually be set in a position to ensure $N_2 = N$ for the average load to be carried by the machine.

The machine would not be built as shown in Fig. 1, where the field excitation circuit is directly connected to the armature terminals, because of constructional difficulties consequent on the

enforced use of fine wire, etc. Step-down transformers may be used to reduce the machine voltage to a value convenient for use in the excitation circuit or an auxiliary winding may be used on the armature to obtain the most suitable excitation voltage for the field-circuit. In practice the excitation is arranged for more than three phases.

An alternating current generator of the above described type would find few applications, but it is easy to arrange for the compounding of this machine and it will then prove to be a very

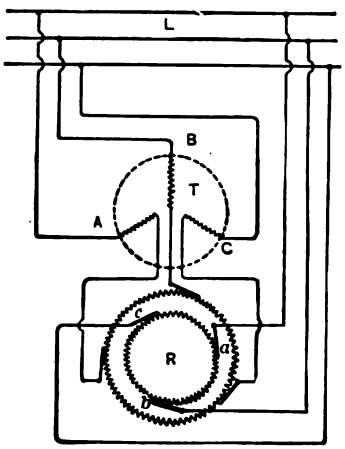


FIG. 5.

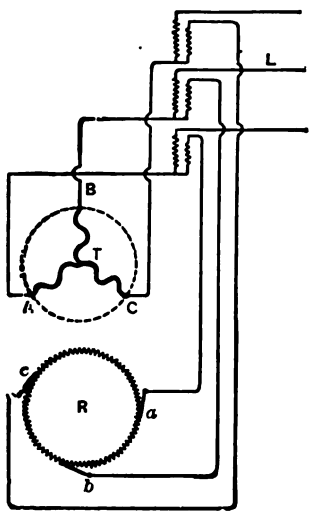


FIG. 6.

interesting type of alternating current machinery, especially in steam-turbine groups.

Consider for a moment the machine represented by Fig. 1 with the brushes fixed in the position corresponding to A o a $\pi/2$. Place a second field-winding on the revolving-field and connect it to a second commutator provided with three sets of brushes connected to the armature-winding at points 120° apart, as shown in Fig. 5. These brushes are now to be fixed in such a position that the ampere-turns of this second field-winding oppose those of the armature, and we can arrange matters so that the armature-flux will be opposed by a field-flux of the same magnitude, direction

and form. A similar arrangement has been proposed by Mr. H. J. Ryan for continuous-current dynamo machinery.

With a machine constructed as above and with the brushes in a fixed position, we will obtain constant frequency of induced armature-currents and the machine will compound for variations in output and power-factor of load—in one or all of the phases.

The same result may be obtained by substituting for the second field winding, commutator, brushes, etc., three compounding transformers, one per phase, as shown in Fig. 6.

By means of these modifications the simple machine of variable frequency has become a constant-frequency machine, which result

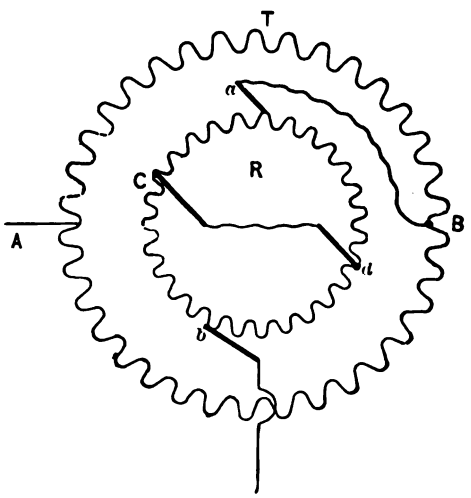


FIG. 7.

could only be attained in the first instance by changing the position of the brushes for variation in non-inductive and inductive loads.

A single-phase simple and compounded machine may be obtained by using two short-circuiting brushes placed at right-angles to the brushes connected to the armature-winding. The same arrangement with armature and field connected in series as shown in Fig. 7, is especially interesting in single-phase traction motors, but the discussion of this line of single-phase machinery is reserved for a future paper.

In view of the probable objections to the use of a commutator in alternating current machinery, it is of interest to note that the commutation is perfect on all the machines which have been tested. Any pulsations in the magnetic flux of the machine are dampened by the field-winding, which is practically short-circuited on the armature-winding by means of the brushes thus constituting a damping-coil. Furthermore, the currents induced by pulsation in the magnetic flux in those positions of the field winding circuit which are short-circuited under the commutator brushes assist energetically in dampening these pulsations. Machines of 50 cycles, 30 to 40 kilowatts output with twelve coils and six commutator segments per pole, give excellent results with three-phase excitation. In large machines it is better to use eighteen commutator segments per pole. In this case the excitation will be hexaphase. In low-frequency machines the excitation will be from seven to nine phases. The dimensions of the commutator may always be made small by a proper choice of the excitation voltage.

The data contained in this hastily prepared paper has been very kindly placed at my disposal by Mr. Marius Latour, who has developed and designed this interesting line of alternating current machinery.

Discussion.

President Scott:—The subject for the meeting this evening is the general subject of Induction Generators. The main paper on that subject, the leading paper, unfortunately, has not been prepared, so that the title of the subject to be considered has been disregarded and we take up several papers relating in general to alternators.

In its simplest form the dynamo consists of an armature and field. The field may be a permanent magnet; it may be an electromagnet. The great evolution in electrical machines came in the introduction of the electromagnet as a part of the field. Ordinarily, the field is a very simple part of the machine excited by direct current, and the variations in the character of the machine, direct current or alternating current, its voltage, its phases, frequency, etc., are dependent on the armature, but there are variations which can be effected in the field itself. The field may be excited by direct current, it may be excited by alternating current; the field magnetic flux may come from the currents which flow in the armature, coming from some auxiliary source. If the field be supplied with an alternating current, we have a new set of relations different from those which we have when the field is excited by direct current. The field alternating current may have different frequencies; may be of a low frequency. The alternating current in the field may be derived from some external source; it may have some synchronous relation with the main frequency. Here, then, we have a variety of conditions for exciting the field by alternating current, and derived from different sources, or by deriving the excitation from a current flowing in the armature itself, which give a new field, a new order of investigation and development and operation to alternating machines.

In one of the simplest forms comes the ordinary induction motor, with a squirrel-cage secondary. That may be used as a dynamo, if the speed be a little above, instead of a little below, the synchronous speed. Again, in the field of an alternator, there may be means for compounding, for increasing the field strength by a current derived from the main current. This gives a new order of relation, so that we have a very interesting and somewhat complicated and intricate set of problems arising from field variations in alternating machines.

The papers this evening have in one phase or another to do with the general problem which I have presented in this meagre and brief way. The first paper of the evening is by Mr. Behrend, who has given much attention to the designing, principles, theory and testing of alternating apparatus. The subject of Mr. Behrend's paper is "The Experimental Basis for the Theory of the Regulation of Alternators."

Mr. Behrend:—Midnight is drawing near and we have before us eighty pages of complex and intricate matter, and I

presume that we do not wish to extend this meeting until the Niagara Falls convention. In justice to the papers that will be read after mine, I want to be brief. I sincerely trust that this will meet entirely with your approval.

(Mr. Behrend then presented an outline of his paper.)

I want to call your attention to one or two matters which I have not had an opportunity to take up in my paper. The great importance of specifying the regulation of alternating current generators in regard to the size, efficiency, operation and cost of the machines is not at all clearly understood by consulting engineers. Besides, we often find specifications calling for conditions which are impossible to fulfil, as they are mutually contradictory of one another. For instance, you can find specifications calling for a regulation of 5 per cent. on a 100 per cent. power-factor, and a regulation of 12 per cent. on an 80 per cent. power-factor, and an increase of excitation of 10 per cent. between normal voltage at no load and normal voltage at 80 per cent. power-factor. Such things are impossible. I have tried to take this matter up in my paper with a view to pointing out a method by which you can convince yourselves as to what conditions are possible to obtain. Furthermore, a regulation which is too good may lead to a low efficiency of the machine and a poor operation in parallel on account of the large cross-currents which would be produced with reciprocating engines.

PRESIDENT SCOTT:—I had the pleasure when in Paris last summer of meeting a young man about my own age, a bright, intelligent man, who looked not unlike an American in his general make-up. He appeared to be a progressive man and probably possessed considerable skill as an experimenter. I was very favorably impressed in meeting him. The gentleman to whom I refer is Mr. Heyland, and the next paper relates to the Heyland motor. Prof. Comfort A. Adams, of Harvard University, will now present the second paper, "A Study of the Heyland Machine as Motor and Generator."

PROF. ADAMS:—I feel considerable diffidence in bringing this paper before the INSTITUTE, partly because the results obtained by experiments which are recorded here do not seem to be of very great practical importance, and partly because the volume of the paper might lead to unlawful expectations. Some one has said the paper looked very attractive. I hope that some of you who take pains to read it will find it attractive, but it is not a subject which is, in detail, probably interesting to the majority of the members of the INSTITUTE, but it has some practical bearings, and as such I hope it will be of some interest.

PRESIDENT SCOTT:—We have had this peculiar alternator problem attacked from various points of view. First, a designer told us a few things he knew about the alternator, and then we have had a Professor who has told us what he knows about it, and now we have another point of view, and that is the point of view of the direct current man who has assumed, we may say,

to know nothing about it, and yet to pronounce judgment upon it. The next paper is by Mr. A. S. Garfield, who writes on "The Compounding of Self-excited Alternating Current Generators for Variation in Load and Power Factor." The writer of the paper is not present and it will be abstracted by one of our members who is an expert in the direct current business, Mr. Gano S. Dunn.

MR. DUNN:—I am sure President Scott wants this abstract to be short. That is why he called on me.

Mr. Dunn then abstracted the paper. (See page 811.)

PRESIDENT SCOTT:—I notice in the list of applicants for admission as an associate of the INSTITUTE the name of Marius Latour, Paris, France, to whose apparatus mention has been made.

The subject is now open for general discussion if any one is pleased to take part in the discussion.

PROF. ADAMS:—I would add one word to Mr. Behrend's paper which is very interesting to me, dealing with a subject to which I have given much attention. I have made very careful tests on several large machines and on numerous small ones, of various types, and the results are entirely corroborative of Mr. Behrend's results. The e.m.f. method gave almost invariably too poor, and the m.m.f. method too good a regulation. In machines of the inductive type, reactance plays a larger part than armature reaction, and here the e.m.f. method is more suitable, since it is essentially a reactance method whereas with machines in which armature reaction predominates, as in the modern low frequency alternator, the m.m.f. method is more suitable; but even when the method is chosen to suit the type of machine, the results are very wild, and some compromise between the two methods must be employed.

MR. WILLIAM L. WATERS:—Clause 71 in the Recommendations of the Committee on Standardization, which deals with the regulation of alternators, is, I think, more or less of a makeshift and a confession on the part of the Committee of their inability to formulate an exact method of determining the regulation of an alternator from any other than a full load test. It is well known to every designer that the method therein indicated gives results which, on certain classes of machines, are far too low. I do not know of any accurate method which can be substituted for that load.

By far the best method in guaranteeing the regulation of an alternator is to guarantee it for a low power-factor. As regards the actual operation of the machine, this is far more satisfactory than guaranteeing the regulation on non-inductive load, and in addition it is an easier test to make. By running a test, as described by Mr. Behrend, with two machines, one running as a synchronous motor and the other as a generator, and then adjusting the excitation, a direct reading for the regulation can easily be obtained. This test can quite easily be made even on very large units.

As regards the advisability of having the regulation guaranteed for low power-factors, even in the case of alternators for running rotary converters, I will give an instance of trouble that occurred in a large station with alternators supplying power for rotaries in substations. A breakdown occurred on the high-tension leads of the alternators, causing a temporary shutdown of the plant, so that when the alternators were again run up, the rotaries had to be started from the alternating current side. As soon as the voltage showed up again in the substations, all the attendants threw on their rotaries at the same time, and the result was an immense lagging current, which cut down the volts so that the rotaries refused to start. The attendants seeing this, cut out their rotaries and the volts rose again. This went on two or three times, and in the end it was about three-quarters of an hour before the substations were started again. These alternators had a guaranteed regulation of 7½ per cent. on power-factor 1, and that would satisfy this guarantee if tested according to INSTITUTE rules, but their behavior on low power-factors can be imagined from the above incident.

Coming to Mr. Behrend's paper, he points out very well, I think, that the two empirical methods which he gives for determining the regulation are neither of them accurate, and every designer has to modify these methods in order to obtain satisfactory results on his own individual machines. But I think Mr. Behrend begs the whole question when he uses the Kapp diagram to calculate the regulation on different power factors, assuming the regulation from power factor 0. The Kapp diagram assumes that the self-induction of an armature remains constant for all phases of the armature current, that is, for all relative positions of the armature and magnets. This is a pure assumption, and is in reality by no means correct. Some years ago I did some work on this method of obtaining the regulation of alternators, and measured the self-induction of the armatures of a large number of alternators for different relative positions of the armature and fields, the measurements being made with short-circuited magnet coils. I found that the self-induction varied very considerably according to the relative position of the armature and magnet, and with some machines of very small air gap this variation was of the order of 6 to 1. These measurements, of course, do not accurately represent the condition of things und r load, but they give some idea as to the variation that may take place.

Mr. Behrend closes his paper with an application to direct current machines of this short-circuit method of measuring the armature reaction, and gives an instance in which this gave pretty accurate results. This method of determining the compounding on a direct current machine is very old, and was used with fair success on the old smooth core armature machines. But in modern slotted armature machines with highly saturated teeth the distortion of the fields as caused by armature reaction

makes a large increase in ampere-turns necessary on full load in order to overcome the decreased permeability of the armature, due to this distortion. So that though this method may give fairly good results in a machine in which the tooth density is not over 125,000, it will be very inaccurate in a machine with highly saturated teeth, say a machine with teeth worked at 150.000. The compounding ampere-turns necessary in this latter case would probably be about double that given by the short-circuit method.

MR. BEHREND:—I was very sorry that I had no opportunity to refer to Prof. Adams' very interesting papers in the Harvard *Engineering Journal.* Prof. Adams was so kind as to send me a copy of his papers which, however, did not reach me until a day before I left Cincinnati for New York, otherwise, I should have taken great pleasure in referring in my paper to his work along the same lines, as I entirely agree with the results obtained and the methods in his paper. I deem it a pity that papers of such quality are not published in our TRANSACTIONS, but in journals like the Harvard *Engineering Journal*, which do not, as a rule, come to our notice. We might add such papers to the very long list of the papers we have to read, but few of us can find time to read the journals that we already have.

In regard to the remarks of my friend, Mr. Waters, I think he pointed out one of the principal weaknesses of my paper. He said that I arbitrarily applied the Kapp diagram to the determination of the regulation at different power-factors. It is perfectly true that this is more or less arbitrary, but, as we are continually floundering in a maze of assumptions that are more or less arbitrary in regard to the conditions under which machines have to operate, and in determining their exact dimensions, we have to use engineering intuition to tell us how far we are justified in making such assumptions. I have pointed this out in my paper to-night and I have pointed it out invariably in my other papers treating of matters connected with electrical engineering, and especially in my treatise on " The Induction Motor." Electrical engineering, in my mind, is an art and not a science. As you cannot teach any one to make a good picture if he has not the aptitude, so you cannot teach a man how to design an electrical machine. It is a question of engineering judgment and intuition. If engineering methods, as set forth in my paper, fall into the hands of men without judgment, the results are the same as if you put a knife into the hands of a bungling surgeon.

[COMMUNICATED AFTER ADJOURNMENT BY J. R. ARMSTRONG.]

In last Tuesday's meeting, when the time came for general discussion of the subject, it really was so late I did not care to criticise some of the points brought up. However, there is just one point in the papers that were read which ought not to stand without criticism; I mean the sacrifice of regulation for efficiency. The writer of each paper seemed to consider that in the

design of an alternator the all important factor was the obtaining of high efficiency. To regulation they paid very little attention. This latter seemed to be considered a very secondary matter.

Suppose we consider a 60,000 volt long-distance transmission line; one central station and two substations; one substation being 50 miles distant from the central station and the other 10 miles. Now, if one of these substations, say the 10 mile one, should be cut off suddenly, there would be a certain rise in voltage at the central station. This rise would be magnified greatly at the other end of the 50 mile line, on account of the condenser effect in the line. This increase in voltage would be liable to cause trouble at this second substation that is still running. I therefore think that if designers would sacrifice a few per cent. efficiency in a machine and obtain better regulation, it would reduce a great deal of such trouble as might arise in the above-mentioned case. I therefore think that, in future, more importance ought to be given to regulation in the design of alternators.

[COMMUNICATED AFTER ADJOURNMENT BY MARIUS LATOUR.]

In the paper of Mr. Adams read May 19th, 1903, he appears to recognize several distinct methods for compounding alternators provided with a commutated winding. In fact, these several methods are very similar for the simple reason that a compound excitation can only consist of the combination of a series and of a shunt excitation.

The most natural method of carrying out this combination in practice is to arrange two circuits and two commutators on the rotor. But it is easy to see that the use of a compensating transformer is an equivalent.

For example, when using two circuits and two commutators, assume that the series excitation current is obtained from a series transformer K, as is shown in Fig. 1. where the series circuit is alone represented. It is evident that by suitably setting the brushes $a\ b\ c$ the armature reaction can be annihilated in both direction and form.

If the self induction of each secondary of the series transformer K with three-phase connections is represented by l, the ohmic resistance of one-phase of the excitation circuit by r and the frequency of induced currents by w the brushes should be set in such a place as to give:

$$A\,o\,a = \frac{\pi}{2} \times A\,g^{-1}\,\frac{l\,w}{r}$$

In order to obtain the shunt excitation without the addition of a second winding, we can arrange matters in such a manner that the shunt currents pass through the secondaries of the transformer K (see Fig. 2), these circuits being now closed on the stator winding in place of the special connection of Fig. 1. The secondaries of the series transformer K may be closed on the stator before or

after the primaries and in either case the secondaries of this transformer constitute impedances for the shunt currents. The currents therefore lag by an angle $t\,g^{-1}\frac{l\,w}{r}$ and the machine behaves as if the brushes $a\ b\ c$ were placed, for shunt excitation, in the position $A\ o\ a = \frac{2}{\pi} + t\,g^{-1}\frac{h\,r}{r} - t\,g^{-1}\frac{h\,r}{r} = \frac{2}{\pi}$ and as if the machine were run light all the time. The flux of the armature is annihilated both in direction and form at any load. The machine operates practically at synchronism.

Mr. Adams is certainly in error in saying: (1) That it is impossible to compound rigorously for all loads by means of a com-

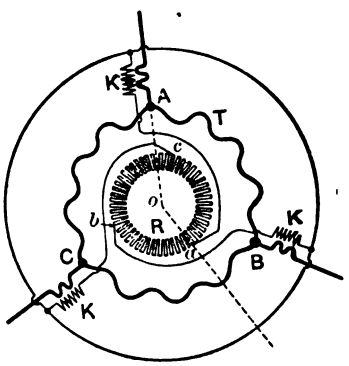


Fig. 1

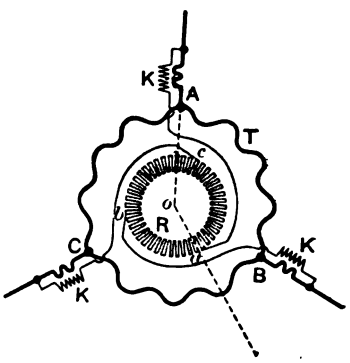


Fig. 2

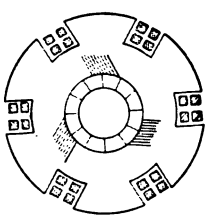


Fig. 3

pensating transformer and, (2) That the machine could not induce currents at constant frequency.

To obtain these two desiderata it suffices properly to design the transformer K, which, in any case, is of small dimensions. The compensating transformer is my way of compounding the shunt machine.

Concerning my shunt machine working as a motor, it is of interest to read the article of Mr. Bragstad, see *E.T.Z.*, May 21st, 1903.

The commutation of alternators of my design, in which I make use of the ordinary winding of the continuous current armatures

is as good with few bars on the commutator as with many. With a drum winding consisting of twelve coils divided into six slots per complete magnetic circuit (see Fig. 3), the commutation is perfect. The damping of harmonics is produced automatically not only by the short-circuiting of the rotor through the exciting circuit, as before indicated by myself (see *Electrical World*, 1902 page 60), but also by the short-circuiting of the rotor coils through the brushes.

These two ways of damping of harmonics which I have personally discovered are more than sufficient to suppress every harmonic and to give a perfect commutation.

Instead of placing the coils in one slot only it is possible to put them in several slots per hole, as proposed by Mr. Fischer-Hinnen for continuous current dynamos.

DISCUSSION AT PITTSBURG, JUNE 4, 1903.

MR. LINCOLN:—I would like to ask Mr. Olin about one point. It was originally thought that since poor regulating machines do not have so large short circuit current they would not raise so large a disturbance when short circuited. The machines at Niagara Falls, with which I am familiar, are not particularly good in regulation, but I know from experience that they can raise a great deal of a rumpus when short circuited. Enough current can come out those machines on the instant of short circuit to throw the cables off the brackets, with only a single machine on the circuit. The mechanical force required to throw the cables apart in the manner noted would indicate 20 to 30 times full load current at the instant of short circuit instead of two or three times, as it would be after the short circuit has been on for some time.

PROFESSOR KARAPETOFF:—Some time ago I was interested in the principles of action of the Heyland motor, and I tried to find out for myself some simple theory of its working. You will allow me to occupy a few minutes of your time, to expound to you in a simple way some properties of the Heyland machine. The Heyland motor is an induction motor, which can work at a power factor of unity and for this purpose its rotor is provided with a d.c. commutator and brushes.

The tendency during the last few years has been to get a motor, requiring as little attention as possible. An ordinary induction motor with a short circuited rotor satisfies this condition to a very large extent. But having attained simplicity we have deprived ourselves of every means of regulation of the power factor or of the speed. Now, if we wish to control the power factor, as in a synchronous motor, or its speed, as in d.c. motors, we must introduce a new part into our machine.

In the Heyland motor the brushes can occupy different positions on the commutator and they constitute the movable part by which the power factor of the motor can be regulated and by which it not only can be raised to unity, but even leading currents can be produced in the line, as in the case of an over-excited synchronous motor.

In an ordinary induction motor the magnetizing current, which produces the resultant rotating flux in the air-gap, is supplied to the stator as a component of the primary current; this wattless component makes $\cos \varphi$ of such a motor less than 1. In the Heyland motor an additional component of the rotating field is produced by the currents introduced into the rotor by the brushes. The phase of this additional component can be regulated by changing the position of the brushes; in this way the total magnetizing current can be regulated both in its phase and value, so as to suit our purposes.

At speeds near synchronism, at which the Heyland machine should be ordinarily used both as motor and as generator, the

armature can be considered almost as an ohmic resistance; this explains a very low-tension sufficient at the brushes and following a small amount of energy for magnetization. Practically this low-tension is produced either by special autotransformers, or simply by shunting leads to the brushes from a part of the stator windings, thus using these windings as autotransformers.

The possibility of regulating cos φ is given by a movable adjustment of the brushes.

The speed of the motor can be very simply regulated by changing the pressure at the brushes; for this purpose the autotransformers can be provided with several taps.

It is not necessary to prove that the Heyland motor can work as an induction generator above synchronism; it does it on the same principle as an ordinary induction motor. The only thing to be shown is that the Heyland generator can be self-exciting, while an ordinary induction generator always requires some synchronous generator working with it in parallel and supplying magnetizing currents for its rotating flux.

The disadvantage of having a commutator does not seem to me to be very serious; the pressure at the brushes is comparatively very low and the current introduced through the commutator is only a small part of the secondary current induced in the short circuited windings of the rotor. Mr. Heyland says in one of his articles, that the commutator of his machine is only 5 per cent. of the size of the commutator of a d.c. motor of the same horse-power. The number of segments can also be made small.

MR. LINCOLN:—Are the Heyland motors used to any large extent?

PROFESSOR KARAPETOFF:—I have never seen these motors and am only interested in the development of the idea.

MR. SCHMIT:—European firms in Austria do not put them on the market as they are too complicated and require too much skilled attention.

MR. LINCOLN:—Is there any trouble from sparking at the brushes?

PROFESSOR KARAPETOFF:—Mr. Heyland affirms that there is no sparking at all if the resistances are properly adjusted, and points out that the brushes and commutator require only a small amount of energy. There are only eighteen segments in his commutator. It is not necessary to have resistance between all the commutator bars; it is enough to have resistance between some of them.

MR. PECK:—I would like to ask Mr. Olin how his attempts in the testing room to measure the actual regulation of a machine compared with the calculated regulation.

MR. OLIN:—We have made several attempts but never have been able to make the actual regulation check closely with the calculated. The calculation is merely a first approximation, but there is no better way known to get at it.

Meeting adjourned.

A paper read at the 2d extra Meeting of the Schenectady Branch of the American Institute of Electrical Engineers, Union University, Schenectady, New York, May 18, 1903.

A DISCUSSION OF SOME POINTS IN ALTERNATING CURRENT THEORY.

BY W. S. FRANKLIN.

I was bold enough to write several weeks ago to the secretary of the Schenectady Branch of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, suggesting that arrangements be made whereby I might discuss with Mr. Steinmetz some points in alternating current theory with the hope of bringing about among writers on this subject an agreement in regard to certain points in method and notation which would, I think, greatly facilitate educational work in this field.

I was pleased to hear promptly from Mr. Williams that my suggestion had met with the hearty approval of Mr. Steinmetz and that the debate, as Mr. Williams called it, would be set for Monday, May 18. I wish to thank Mr. Steinmetz for his readiness to enter into a discussion with me and I wish to express my high opinion of his ability as a physicist by referring briefly to a short conversation I had with him several weeks ago, a conversation which turned to the discussion of the vacuum tube discharge and of the general question of the relation between temperature and luminous radiation. It pleased me greatly to hear Mr. Steinmetz say that it is a mistake to apply the notion of temperature to the peculiarly disturbed gas in a vacuum tube. I was reminded of the incredulity with which a fellow physicist received a statement from me some six or seven years ago, when we were discussing the question of the temperature of the electric arc—I stated that the arc has no temperature, though it cannot be denied that it is in a certain sense very hot. Mr. Steinmetz's remark also reminded me of a criticism I made several years ago of Duhem's large treatise on Thermodynamics. I took occasion

in reviewing this book to point out a mistaken mathematical development based by Duhem on the false application of the precise notion of temperature to a body or system not in thermal equilibrium. Duhem contended, largely on the basis of this error, that his notion of thermodynamic potential is more definitely usable in thermodynamic theory than the notion of entropy.

Before proceeding to the details of the evening's discussion I wish to state that my discussion will be very largely a discussion of ideas and conceptions with little reference to detailed mathematical developments. I know of only one way to carry on such a discussion and that is to reduce each point in the discussion to its simplest terms and state the result as a fact. One of the General Electric employees said to me some time ago that the trouble with Mr. Steinmetz was that he threw out his statements expecting them to be accepted as self-evident statements of fact. Truly, I cannot see how else Mr. Steinmetz could do. For my part I shall of course endeavor to make my statements as clear as possible, nevertheless I think that the auditors are in for a very considerable share of the effort of the evening's discussion.

My primary object in opening this discussion is to state my position clearly on the following points:

(a) Steinmetz's polar-coördinate method versus the clock-diagram method of representing harmonic alternating electromotive forces and currents.

(b) The necessity of choosing signs, especially in polyphase networks, in order that the physical facts of a problem may be fully and unequivocally represented in the vector diagrams or in the complex equations which form the basis of the solution of the problem.

(c) That Mr. Steinmetz's topographical method does not differ in any essential respect from the vector method of representation, and that Mr. Steinmetz is not justified in his claim that the topographical method is better suited than the vector method to the discussion of polyphase problems where the consideration of algebraic signs is more exacting than in single-phase problems.

(d) In regard to the physical basis of the general equations of the transformer and of the induction motor.

(e) In regard to Mr. Steinmetz's treatment of power and double-frequency products.

POLAR-COÖRDINATE VS. CLOCK-DIAGRAM METHOD.

I think it is of the utmost practical importance, especially to men engaged in educational work, that the relative advantages and disadvantages of these two methods be carefully considered and that the one or the other together with the corresponding convention as to sign of reactance in the complex expression for impedance be finally and universally adopted.

I take it to be self-evident that a pulsating quantity such as an alternating electromotive force or current can be represented only by a thing which pulsates. We should guard ourselves carefully against falling into the notion that a vector represents an alternating electromotive force or current. At least at the outset when we are developing our method, be it Steinmetz's polar-coördinate method or the clock-diagram method, we should have a clear appreciation of all the machinery involved, afterwards it is of course allowable to say, for the sake of brevity, that a certain vector *represents* a given alternating electromotive force or current without describing how the representation is actually accomplished.

In case of the clock-diagram to say that a given vector E *represents* a harmonic alternating electromotive force means that it is a rotating line of which the projection on a fixed line represents the varying values of the alternating electromotive force.

In case of Steinmetz's polar-coördinate diagram, to say that a given vector E *represents* a harmonic alternating electromotive force means that the vector stands for a circle of which it is the diameter and that this circle cuts off from a rotating line a varying segment which represents the varying values of the alternating electromotive force.

The fundamental machinery of representation being thus devised the next step in the development of either method is to establish the addition theorem, namely, that the sum of two harmonic alternating electromotive forces e' and e'' (instantaneous values) is *represented* by the vector sum of the two lines which *represent* the respective electromotive forces e' and e''.

The establishment of this theorem is an extremely simple matter in the clock-diagram method and although it is not a serious matter in the polar-coördinate method it must be admitted that any junior student is likely to be overwhelmed by the unfamiliar mechanism involved. Stated fully, the theorem is as follows in the polar-coördinate method and clock-diagram method respectively:

(a) Two harmonic electromotive forces e' and e'' are represented by the varying segments cut off from one and the same rotating line by two fixed circles of which the diameters are the lines E' and E''. Then the sum $e'+e''$ is represented by the varying segment cut off from the same rotating line by a fixed circle of which the diameter is the vector sum of the two lines E' and E''.

(b) Two harmonic electromotive forces e' and e'' are represented by the varying projections of two lines E' and E'', which rotate at the same speed. Then the sum $e'+e''$ is represented by the varying projection of the vector sum of E' and E''.

I am convinced that neither the clock-diagram method nor the polar-coördinate method has any essential advantage over the other except, perhaps, that the clock-diagram method is more simply related to the fundamental geometrical interpretation of the complex expotential $E\,\epsilon^{j\omega t}$ as a uniformly rotating vector of length E.

I am convinced that the machinery of the clock-diagram method is much more familiar to every one and simpler than the machinery of the polar-coördinate method.

I consider that the difference in the complex expression of an impedance, namely, $r+jx$ and $r-jx$, which grows out of the differences in the machinery of the polar-coördinate and of the clock-diagram methods is a very serious source of confusion and vexation. I think that we ought all to adopt the clock-diagram method, and the expression $r+jx$ for the impedance of an inductive circuit. I think that all questions of notation are essentially educational questions and I therefore feel justified in taking a stand in this matter in apparent opposition to Mr. Steinmetz. I say apparent opposition because I cannot imagine that Mr. Steinmetz cares anything about the matter except to the extent that he is concerned with the business of education and to that extent he must, I think, agree with me.

Before leaving this discussion of the polar-coördinate method and the clock-diagram method, I wish to call attention to a matter which, in both methods, is more or less perplexing, namely, the question as to the propriety of representing impedance as a vector. In the clock-diagram, electromotive force and current vectors are understood to rotate, while an impedance vector, if one chooses to represent impedance by a vector, is stationary. It is therefore not proper to represent impedance

by a vector in one and the same diagram with electromotive force and current. In the polar coördinate diagram it is perhaps allowable to represent both impedance and electromotive force or current, it being kept in mind that an electromotive force or current vector stands for a circle and the accompanying machinery for representing a harmonically varying quantity while the impedance vector does not.

NECESSITY OF CHOOSING SIGNS IN COMPLICATED NETWORKS.

Everyone appreicates the importance in general of representing the data of a problem completely and without ambiguity in the geometrical construction in the algebraic formula which is to be used in solving the problem. The choice of signs in a complex network is a matter which touches this general question and I wish to speak especially of the choice of signs in polyphase networks inasmuch as I do not, so far as I see, agree with Mr. Steinmetz in this matter.

In considering a single-phase alternator the electromotive force (or current) can be represented by a given line or by a line in the reverse direction according as we choose to consider the electromotive force as positive or negative when it acts in a given direction. This ambiguity, however, seldom or never leads to confusion in the study of single-phase circuits inasmuch as we quite unconsciously choose the positive direction of electromotive force to coincide with the positive direction or current, and in the study of a single-phase circuit we are concerned only with the relations between the one electromotive force and the one current. When we come, however, to consider a polyphase system we are immediately confronted with the relationship of electromotive forces (or currents) in different circuits and an explicit decision as to signs is absolutely necessary. I gave to-day, before the students of Union College, an elementary discussion of a number of simple problems illustrating this point; namely, (a) the electromotive force and current relations in a two-phase three-wire system. (b) The electromotive force and current relations in Y and $\triangle$ connected three-phase alternators. (c) The use of two wattmeters on a three-phase receiving system. (d) The use of two transformers for 3-phase = 3-phase step-down transformation, and (e), the 2-phase 3-phase transformer. I give the most important features of this discussion in an appendix to this printed discussion so as to furnish several examples illustrating the necessity of the choice of signs.

I think that Mr. Steinmetz is wrong in claiming any advantage of his so-called topographical method over the vector method in the clearing up of difficulties arising from the confusion of signs, and I think that the distinction between action and reaction, between impressed electromotive force and counter-electromotive force, although it complicates the difficulties arising from confusion of signs, is a very different matter from that which I have in mind in the above discussion.

The topographical method really contains not the least element of essential difference from the vector method of representation. The two methods differ chiefly in their appeal to the eye and I think that Mr. Steinmetz has been led to attribute greater power to the topographical method for the following reason:

In ordinary alternating current problems we are in nearly all cases concerned with the *addition* of given partial electromotive forces or currents, while in many polyphase problems we are frequently concerned with the *subtraction* of given electromotive forces or currents. Now we are all of us accustomed to picture mentally the sum of two vectors as the diagonal of the parallelogram constructed on the two vectors as sides, but we are not so accustomed to picture the difference of two vectors as the distance between their termini. On the other hand, if only the *terminal points* of two vectors are indicated in a drawing the distance between the points is the simplest notion that can be associated with them. That is, the topographical method accentuates the notion of a difference and in fact this accentuation is not accomplished by making the notion itself more evident in the diagram but by making the notion of a sum less prominent.

I am convinced that the topographical method of Mr. Steinmetz is essentially identical to the vector method, except in the way it appeals to the eye. I think that in its appeal to the eye the topographical method is very decidedly less intelligible than the vector method and I do not think even that the topographical method permits more readily than the vector method of the use of a reference point or region of zero potential. I wish to take this occasion to say that I wholly disapprove of those so-called vector diagrams so frequently used by writers on alternating currents, not however including Mr. Steinmetz, in which the various electromotive forces or currents are represented by sides of triangles without arrow heads. All electromotive force or current vectors should be drawn from one and the same origin and each should have an arrow head. Uncertainty as to which

end of a vector should show the arrow head simply means that the person who is constructing the diagram does not know enough about the concrete facts of his problem to represent them completely and unequivocally in a vector diagram.

THE FUNDAMENTAL EQUATIONS OF THE TRANSFORMER AND OF THE INDUCTION MOTOR.

There is nothing in the teaching of physics so important as to develop in the student the ability to express physical conditions in mathematical form, geometrical or algebraic as the case may be; to reproduce or represent the conditions of a problem adequately as a geometrical construction or as an algebraic formula. Nothing, I say, is so important as this. It is the very essence of effective knowledge in physics, and every bit of attempted instruction which does not contribute directly or indirectly to facility in this representation of physical fact, in terms of our mental tools, is, in my opinion, futile. I think that no one but a teacher of physics can fully appreciate the truth of these assertions and it is far from my intention to criticise Mr. Steinmetz's writings for their meagreness in this respect. Mr. Steinmetz has a right to expect of his readers some degree of facility of the kind here under consideration, and I for one am always glad when I take up a theoretical paper which does not impose a great array of elementary detail upon my attention. I can stand unlimited preliminary statement of fact even when the style is slightly obscure, but reiterate explanation I cannot endure. If anything in this statement be taken by my hearers as a suggestive criticism of Mr. Steinmetz's papers I hasten to assure you of your mistake, although I must admit that Mr. Steinmetz's style has sometimes seemed to me to be slightly obscure. But let us come to the point. Mr. Steinmetz in his discussion of the general equations of the transformer is led by these equations to a series of propositions as to the equivalence of a transformer with its secondary receiving circuit to various series and parallel combinations of simple circuits. Every one of these propositions in my opinion is easily established by the consideration of very simple physical principles, and I think that the general equations of the transformer are properly based upon these propositions which Mr. Steinmetz seems to think are arrived at by means of the general equations.

If these propositions are really dependent upon the general equations of the transformer I certainly do not know where these

general equations come from, nor on what basis of physical fact they stand.

The theory of the transformer may be developed first on the assumption that coil resistances, magnetic leakage and magnetizing current are entirely negligible. This ideal theory, if we may call it such, is of course very simple. The fact is that this ideal theory is the first term in a series of approximations. A second approximation may be arrived at by considering the effects (a) of coil resistances, (b) of magnetic leakage and (c) of eddy current and hysteresis losses and core reluctance, each by itself, the mutual effects of these three items being ignored. This second approximation is accurate enough to meet every demand hitherto made by the practical engineer. The third approximation, which would have to be based on the consideration of the influence of (a) on (b), of (b) on (a), of (b) on (c), of (c) on (b), of (a) on (c) and of (c) on (a), had never been fully worked out so far as I know.

By considering the effects of items (a), (b) and (c) separately, the propositions enunciated by Mr. Steinmetz are easily established and from these propositions the general equations of the transformer can be written down at once.

The general equations may be, and usually are, modified so as to take account *partially* of the influence of items (a) and (b) upon item (c) by using primary induced electromotive force instead of primary impressed electromotive force in the equation for magnetizing current.

The establishment of the fundamental equations of the induction motor, single-phase, and polyphase, and of the repulsion motor, is, in my opinion, accomplished in much the same manner as the establishment of the fundamental equations of the transformer: that is, by first establishing certain simple circuit equivalences by considering separately the effects of magnetic leakage, coil resistances, core losses, etc.

Power and Double Frequency Products.

The product of instantaneous values of an alternating current and electromotive force gives instantaneous power. This instantaneous power reduces to the form

$$p = a + b \sin (2\omega t + \theta)$$

That is, the instantaneous power consists of a constant part $a\,(= E I \cos \theta)$ and a harmonic part which has a frequency

twice as great as that of the given electromotive force and current.

The question is, can this power p be represented by a vector or by the complex algebraical expression for a vector? I think it cannot. In the ordinary vector representation of an alternating electromotive force three elements are involved, two of which appear explicitly in the vector, namely, numerical value and phase; and one of which, the frequency, is involved in the machinery for which the vector stands. Now p contains four elements, namely, a, b, ωt and θ and it cannot be represented by a vector.

It is possible by means of Hamilton's notion of vector products to see the complete representation of $a+b\sin(\omega t+\theta)$ in the product of the two vectors E and I, which represent electromotive force and current respectively, although a difficulty arises in that the vector which represents $b\sin(\omega t+\theta)$ lies out of the plane containing E and I. A more serious difficulty is, I think, that in Hamilton's system the products of the component unit vectors i, j and k are interpreted in a manner which is inconsistent with the interpretation of the product of the horizontal unit vector i and the vertical unit vector j, upon which ordinary complex algebra is based.

In forming the product of the ordinary complex expressions for an alternating electromotive force and an alternating current *it is necessary to adopt a new kind of complex algebra* in order that any part of the product may represent the power developed. The ordinary complex algebra is not available. I do not think that Mr. Steinmetz's discussion of power and double-frequency quantities furnishes a consistent algebra for representing power and I do not think it is advisable or desirable to develop an algebra to meet the requirements of power representation.

Aside from the fundamental impossibility of representing by a vector a notion involving four elements, I note in particular two things to which I take exception in Mr. Steinmetz's discussion, namely,

(*a*) The fundamental equations of interpretation

$$j^2 = +1$$
$$1 \times j = -j$$
$$j \times 1 = j$$

which, according to Mr. Steinmetz, establish an algebra which meets the requirements of power representation do not, I think, furnish the basis of any consistent system of algebra whatever.

The first of these equations seems to be suggested by the fact that a time interval or angle which represents half a cycle for a given frequency represents a whole cycle for double-frequency. The second and third seem to be suggested by the necessity of bringing into the product of two complex expressions those signs which are required to make one part of the product actually equal to the constant part of the power.

(b) The real component of power in Mr. Steinmetz's discussion is the quantity a in the equation

$$p = a + b \sin (2\omega t + \theta)$$

and the imaginary component is the quantity $b \sin (2\omega t + \theta)$. I do not see what possible meaning can be assigned to a vector of which one component is a constant and the other a harmonic function.

APPENDIX.

Examples Illustrating the Necessity of a Careful Choice of Signs in Problems Dealing with Polyphase Networks.

SINGLE-PHASE SYSTEM.

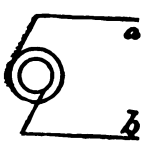


FIG. 1.

Fig. 1 represents a single-phase alternator with its terminals a and b. Suppose that at a given instant the electromotive force acts from a to b at, say, its maximum value. The rotating vector which represents the electromotive force must, at the given instant, be in the position to give its maximum projection but whether in position to give maximum positive or maximum negative projection depends upon whether we choose to consider an electromotive force from a to b as positive or negative. The same remarks apply to the representation of the current delivered by the alternator. If only we choose positive direction of electromotive force and positive direction of current the *same* the relative positions of the electromotive force vector and current vector will be independent of *which* direction is chosen as the positive direction. Therefore no ambiguity can exist provided the same direction is chosen as positive direction both of current and of electromotive force, and the interpretation of the vector diagram is not liable to confusion. This is, however, not the case when we are concerned with the relations

between electromotive forces and currents existing in the separate windings of a polyphase generator.

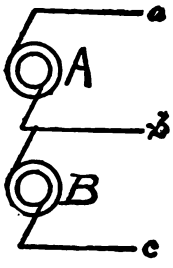


FIG. 2.

TWO-PHASE SYSTEM.

Fig. 2 represents a two-phase alternator with three-wire service mains a, b and c. (The confusion of signs can only occur where the two phases are brought into relation with one and the same element, be it a common main as in this example, a common magnetic element as in the two-phase induction motor, or any other element common to the two-phases.)

Suppose positive signs between mains be chosen from a to b, from b to c and from a to c; and suppose that Fig. 3 is the vector diagram representing the two electromotive forces. Then the electromotive force from a to c is the sum of A and B and it is 45° ahead of B and 45° behind A in phase. If positive signs between mains are chosen from b to a, from b to c and from a to c then with precisely the same actual conditions existing in the system the vector diagram will be as shown in Fig. 4 and the electromotive force from a to c, which is of course exactly the same as before, both in fact and in representation, will be equal to $B - A$, and it will be 45° ahead of B as before and 315° ahead of A in phase.

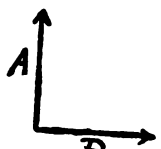


FIG. 3.

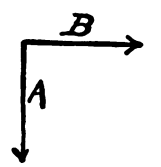


FIG. 4.

Examples of variation of vector diagram with choice of signs along the mains could be easily outlined in the matter of the relations between currents in the mains.

THREE-PHASE SYSTEM.

I shall not take in this case the simplest examples to illustrate the principles under discussion, the examples namely which are furnished by the discussion of current and electromotive force relations in a three-phase three-wire system with Δ-connected and with Y-connected armature windings; but I will take up the discussion of a problem which offers greater intrinsic interest; namely, the problem of the use of two wattmeters for measuring the power delivered to a three-phase receiving system.

THE USE OF TWO WATTMETERS FOR MEASURING THREE-PHASE POWER.

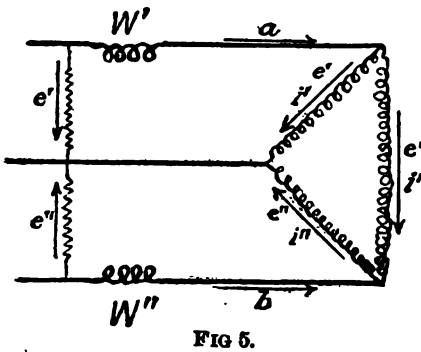


FIG 5.

Fig. 5 shows two wattmeters connected for measuring power delivered to a Δ-connected 3-phase receiving system. In order that the reading of each wattmeter may be considered as positive when the power it measures is *delivered to* the receiving system, the positive signs of electromotive forces e' and e'' and of currents a and b must be properly chosen.

There are four systems of signs which meet these requirements, and each of these systems is non-symmetrical with respect to the three receiving circuits. One of these systems of signs is shown in Fig. 5. The choice of sign of e''' and i''' may be made arbitrarily.

Now, a symmetrical choice of signs in a three-phase system gives a symmetrical vector diagram and a non-symmetrical choice of signs gives a non-symmetrical vector diagram. To fix the vector diagram for a given non-symmetrical choice of signs it is best first to choose a symmetrical system of signs, draw a symmetrical vector diagram, and then change signs as desired and reverse the corresponding vectors.

Fig. 6 shows the vectors which represent the three electromotive forces e', e'', and e''' and the three currents i', i'' and i''' in conformity with the choice of signs in Fig. 5.

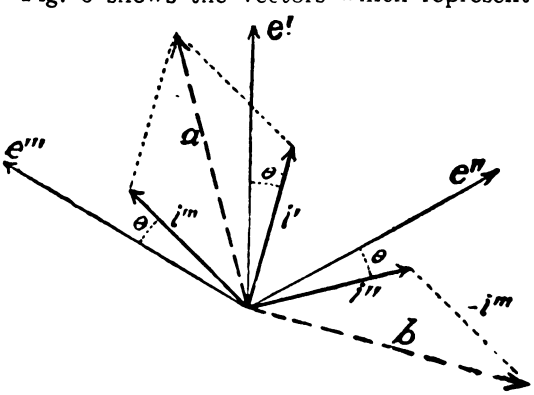


FIG. 6.

By inspecting Fig. 5 it is evident that

$$a = i' + i'''$$
$$b = i'' - i'''$$

from which the vectors representing the currents a and b may be drawn as shown in Fig. 6.

Now, wattmeter W' indicates the average value of the product of e' and a, which is equal to $E'A\cos(30°-\theta)$; and wattmeter W'' indicates the average value of the product or e'' and b which is equal to $E''B\cos(30°+\theta)$; where E', E'', A and B are the effective values of e', e'', a and b respectively. If the receiving system is balanced $E' = E''$ and $A = B$ so that the two wattmeter readings may be written:

$$W' = k\cos(30°—\theta)$$
$$W'' = k\cos(30°+\theta)$$

When $\theta = 60°$ we have the well-known condition in which $W'' = 0$ and the wattmeter W' measures all the power. When $\theta > 60°$ W'' is negative and is to be subtracted from W' to give the power delivered to the receiving system.

INDEX.

BUSINESS OF THE INSTITUTE.

Annual Business Meeting, New York, May 19, 1903 479
Annual Dinner of the INSTITUTE at New York, February 9, 1903 ... 97
Balance Sheet, Secretary's 485
Board of Directors, Report of 480
Boston Branch, Meeting, March 26, 1903 197
Business Meeting, Annual, New York, May 19, 1903 479
Chicago Branch, Meeting, April 7, 1903 307
Chicago Branch, Meeting, May 5, 1903 457
Chicago Branch, Meeting, May 19, 1903 73
Deaths during the Year 484
Dinner, Annual, at New York, February 9, 1903 97
Dinner, Library, at New York, February, 9 1903 97
Directors, Report of Board of 480
Disbursements and Receipts 485
Engineering Building, Union 483, 486
INSTITUTE, Receipts and Disbursements 485
Library Dinner at New York, February 9, 1903 97
Speech by President Scott 97
Speech by Andrew Carnegie 105
Speech by Schuyler S. Wheeler 110
Speech by R. R. Bowker 114
Speech by J. S. Billings 118
Speech by Theodore L. De Vinne 120
Speech by James C. Bayles 124
Meeting, Annual Business, New York, May 19, 1903 479
Meeting, Boston Branch, March 26, 1903 197
Meeting, Chicago Branch, April 7, 1903 307
Meeting, Chicago Branch, May 5, 1903 457
Meeting, Chicago Branch, May 19, 1903 73
Meeting, Minneapolis Branch, March 6, 1903 208
Meeting, Minneapolis Branch, April 3, 1903 298
Meeting, Minneapolis Branch, May 1, 1903 476
Meeting, New York, January 23, 1903 1
Meeting, New York, February 27, 1903 129
Meeting, New York, March 27, 1903 229
Meeting, New York, April 17, 1903 327
Meeting, New York, April 24, 1903 403
Meeting, Philadelphia Branch, March 9, 1903 209
Meeting, Philadelphia Branch, April 6, 1903 301
Meeting, Philadelphia Branch, May 11, 1903 469
Meeting, Pittsburg Branch, February 5, 1903 84
Meeting, Pittsburg Branch, March 12, 1903 220
Meeting, Pittsburg Branch, April 9, 1903 312
Meeting, Pittsburg Branch, May 11, 1903 462
Meeting, Pittsburg Branch, June 4, 1903 586
Meeting, St. Louis Branch, May 16, 1903 467
Meeting, Schenectady Branch, March 17, 1903 224

Meeting, Schenectady Branch, April 7, 1903 299
Meeting, Schenectady Branch, May 18, 1903 589
Meeting, University of Illinois Branch, February 7, 1903 84
Membership, Resumé of 484
Minneapolis Branch, Meeting, March 6, 1903 208
Minneapolis Branch, Meeting, April 3, 1903 298
Minneapolis Branch, Meeting, May 1, 1903 476
New York, Meeting, January 23, 1903 1
New York, Meeting, February 27, 1903 129
New York, Meeting, March 27, 1903 229
New York, Meeting, April 17, 1903 327
New York, Meeting, April 24, 1903 403
New York, Meeting, May 19, 1903 479
Officers Elected 486
Philadelphia Branch, Meeting, March 9, 1903 209
Philadelphia Branch, Meeting, April 6, 1903 301
Philadelphia Branch, Meeting, May 11, 1903 469
Pittsburg Branch, Meeting, February 5, 1903 84
Pittsburg Branch, Meeting, March 12, 1903 220
Pittsburg Branch, Meeting, April 9, 1903 312
Pittsburg Branch, Meeting, May 11, 1903 462
Pittsburg Branch, Meeting, June 4, 1903 586
Portrait of Charles F. Scott, President of the INSTITUTE 1902–1903 (FRONTISPIECE)
President Charles F. Scott, Portrait of ..... (FRONTISPIECE
Receipts and Disbursements of the INSTITUTE 485
Report of Board of Directors for Year ending April 30, 1903 480
Report of Tellers 486
Report of Treasurer 486
Registrations during Year 484
Resumé of Membership 484
St. Louis Branch, Meeting, May 16, 1903 467
Schenectady Branch, Meeting, March 17, 1903 224
Schenectady Branch, Meeting, April 7, 1903 299
Schenectady Branch, Meeting, May 18, 1903 589
Scott, Charles F., President of the INSTITUTE 1902-1903, Portrait of, (FRONTISPIECE)
Secretary's Balance Sheet 485
Speech by President Chas. F. Scott, at Annual Dinner 97
Speech by Andrew Carnegie 105
Speech by Schuyler S. Wheeler 110
Speech by R. R. Bowker 114
Speech by J. S. Billings 118
Speech by Theodore L. De Vinne 120
Speech by James C. Bayles 124
Teller's Report 486
Treasurer's Report 486
Union Engineering Building 483, 486
University of Illinois Branch, Meeting, February 7, 1903 84

PAPERS AND DISCUSSIONS.

Alternating-Current Generators, Self-Excited, Compounding of, for Variation in Load and Power-Factor. (Illustrated.) 569
Alternating-Current Theory, Discussion of Some Points in. (Illustrated.) 589
Alternating-Current Transmission Line, Model Showing Distribution of Electromotive Force and Current along a Single-Phase 261
Alternators, Experimental Basis for the Theory of the Regulation of. (Illustrated.) 497
Arcophone, The. (Illustrated.) (*R. A. L. Snyder.*) 93
Automatic Telephone Operator. (Illustrated.) (*William J. Hammer.*) 31
Axle Lighting. (*Elmer A. Sperry.*) 155
Axle-Light System of Train Lighting. (Illustrated.) (*Arthur J. Farnsworth.*) 163
Burning of Wooden Pins on High-Tension Transmission Lines. (Illustrated.) (*C. C. Chesney.*) 253
Car Lighting System, Electric. (Illustrated.) 133
Central Station Development, Tendencies of 403
Central Stations and Sub-stations, Safety Devices in 417
Central Stations, Economical and Safe Limits in the Size of 407
Central Station, Multiple versus Independent Operation of Units and. (Illustrated.) 425
Communication after Adjournment, Discussing Alternating-Current Machines, by J. R. Armstrong 582
Communication after Adjournment, Discussing Alternating-Current Machines, by Marius Latour 583
Communication after Adjournment, Discussing High-Tension Transmission Lines, by J. R. Armstrong 296
Communication after Adjournment, Discussing High-Tension Transmission Lines, by Henry Floy 297
Communication after Adjournment, Discussing High-Tension Transmission Lines, by W. N. Smith 295
Communication after Adjournment, Discussing High-Tension Transmission Lines, by F. S. Woodward 296
Communication after Adjournment, Discussing Railway Train Lighting, by J. R. Bibbins 193
Communication after Adjournment, Discussing Railway Train Lighting, by R. Neil Williams 226
Communication after Adjournment, Discussing Telephony, by Sidney Hand Browne 90
Communication after Adjournment, Discussing Tendencies of Central Station Development, by Carl Schwartz 461
Communication, Discussing High-Tension Transmission Lines, by M. H. Gerry, Jr 295
Compounding of Self-Excited Alternating-Current Generators for Variation in Load and Power Factor. (Illustrated.) (*A. S. Garfield.*) 569
Concerning the Telephone Engineer. (*S. G. McMeen.*) 81
Discussion of Some Points in Alternating-Current Theory. (Illustrated.) (*W. S. Franklin.*) 589
Discussion on Alternating-Current Machines, at Pittsburg, June 4, 1903 586
Discussion on High-Tension Transmission Lines, at Chicago, April 7, 1903 307

Discussion on High-Tension Transmission Lines, at Minneapolis, April 3, 1903 298
Discussion on High-Tension Transmission Lines, at New York, March 27, 1903 263
Discussion on High-Tension Transmission Lines, at Philadelphia, April 6, 1903 301
Discussion on High-Tension Transmission Lines, at Pittsburg, April 9, 1903 312
Discussion on High-Tension Transmission Lines at Schenectady, April 7, 1903 298
Discussion on Induction Generators, at New York, May 19, 1903 .. 578
Discussion on Railway Train Lighting, at Minneapolis, March 6, 1903 208
Discussion on Railway Train Lighting, at New York, February 27, 1903 179
Discussion on Railway Train Lighting, at Philadelphia, March 9, 1903 209
Discussion on Railway Train Lighting, at Pittsburg, March 12, 1903 220
Discussion on Railway Train Lighting, at Schenectady, March 17, 1903 224
Discussion on Telephony, at Pittsburg, February 5, 1903 84
Discussion on Tendencies of Central Station Development, at Chicago, May 5, 1903 457
Discussion on Tendencies of Central Station Development, at Minneapolis, May 1, 1903 476
Discussion on Tendencies of Central Station Development, at New York, April 24, 1903 441
Discussion on Tendencies of Central Station Development, at Philadelphia, May 11, 1903 469
Discussion on Tendencies of Central Station Development, at Pittsburg, May 11, 1903 462
Discussion on Tendencies of Central Station Development, at St. Louis, May 16, 1903 467
Discussion on the Telephone Switchboard, at New York, January 23, 1903 55
Discussion on the Telephone Switchboard, at University of Illinois, February 7, 1903 84
Distribution of Electromotive Force and Current along a Single-Phase Alternating current Transmission Line, Model Showing .. 261
Economical and Safe Limits in the Size of Central Stations. (*H. A. Lardner.*) 407
Electric Car Lighting System. (Illustrated.) (*W. L. Bliss.*) 133
Electric Lighting for Cars, System of. (Illustrated.) 197
Electric Train-Lighting, Some of the Problems of 173
Engineer, Telephone, Concerning the 81
Evolution of the Telephone Switchboard. (Illustrated.) (*Thomas D. Lockwood.*) 3
Experimental Basis for the Theory of the Regulation of Alternators. (Illustrated.) (*B. A. Behrend.*) 497
Features of Telephone Traffic and their Effect on Service 73
Fluorescent Substances. (See Phosphorescent.) .....
Heyland Machine as Motor and Generator, Study of the. (Illustrated.) 519
High-Tension Transmission Lines. (Introduction by President Scott.) 229
High-Tension Transmission Lines, Burning of Wooden Pins on. (Illustrated.) 253
Induction Generators 578
Insulator Pin, Mechanical Specifications of a Proposed. (Illustrated.) 233
Insulators, Testing of 229
Lighting, an Axle Light System of Train. (Illustrated.) 163

Lighting, Axle..... 155
Lighting, Electric, System of, for Cars. (Illustrated.)..... 197
Lighting, Railway Train..... 129
Lighting, System, Electric Car. (Illustrated.)..... 133
Mechanical Specifications of a Proposed Standard Insulator Pin. (Illustrated.) (*Ralph D. Mershon.*)..... 233
Model Showing Distribution of Electromotive Force and Current along a Single-Phase Alternating-Current Transmission Line. (*W. S. Franklin.*)..... 261
Multiple versus Independent Operation of Units and Central Stations (Illustrated.) (*Peter Junkersfeld.*)..... 425
Operation of Units and Central Stations, Multiple versus Independent. (Illustrated.)..... 425
Operator, Automatic Telephone. (Illustrated.)..... 31
Phosphorescent and Fluorescent Substance, Radium and Other Radioactive Substances with a Consideration of. (Illustrated.) 331
Pin, Insulator, Mechanical Specifications of a Proposed. (Illustrated.)..... 233
Pins, Wooden, Burning of on High-Tension Transmission Lines. (Illustrated.)..... 253
Power and Telephone Wires, Transposition and Relative Location of. (Illustrated.)..... 245
Power Factor, Compounding of Self-Excited Alternating-Current Generators for Variation in Load and. (Illustrated.)..... 569
Problems of Electric Train Lighting..... 173
Proposed Standard Insulator Pin, Mechanical Specifications of. (Illustrated.)..... 233
Radioactive Substances. (Introduction by President Scott.)..... 327
Radioactive Substances, Radium and Other, with a Consideration of Phosphorescent and Fluorescent Substance. (Illustrated.).. 331
Radium and Other Radioactive Substances with a Consideration of Phosphorescent and Fluorescent Substances. The Properties and Applications of Selenium and the Treatment of Disease by the Ultra-Violet Light. (Illustrated.) (*Wm. J. Hammer.*)... 331
Railway Train Lighting. (Introduction by President Scott.)..... 129
Regulation of Alternators, Experimental Basis for the Theory of the. (Illustrated.)..... 497
Safety Devices in Central Stations and Sub-stations. (*Philip Torchio.*)..... 417
Selenium, Properties and Applications of, and the Treatment of Disease by the Ultra-Violet Light. (Illustrated.) (*William J. Hammer.*)..... 331
Some Features of Telephone Traffic and their Effect on Service. (*J. G. Wray.*)..... 73
Some of the Problems of Electric Train-Lighting. (*George D. Shepardson.*)..... 173
Specifications, Mechanical, of a Proposed Standard Insulator Pin. (Illustrated.)..... 233
Standard Insulator Pin, Mechanical Specifications of a Proposed. (Illustrated.)..... 233
Study of the Heyland Machine as Motor and Generator. (Illustrated.) (*Comfort A. Adams.*)..... 519
Sub-stations, Safety Devices in Central Stations and..... 417
Switchboard, Telephone..... 1
Switchboard, the Evolution of the Telephone. (Illustrated.)..... 3
System of Electric Lighting for Cars. (Illustarted.) (*James F. McElroy.*)..... 197
Telephone Engineer, Concerning the..... 81
Telephone Operator, Automatic. (Illustrated.)..... 31
Telephone Switchboard. (Introduction by President Scott.)..... 1
Telephone Switchboard, the Evolution of. (Illustrated.)..... 3
Telephone Traffic, Some Features of, and their Effect on Service... 73

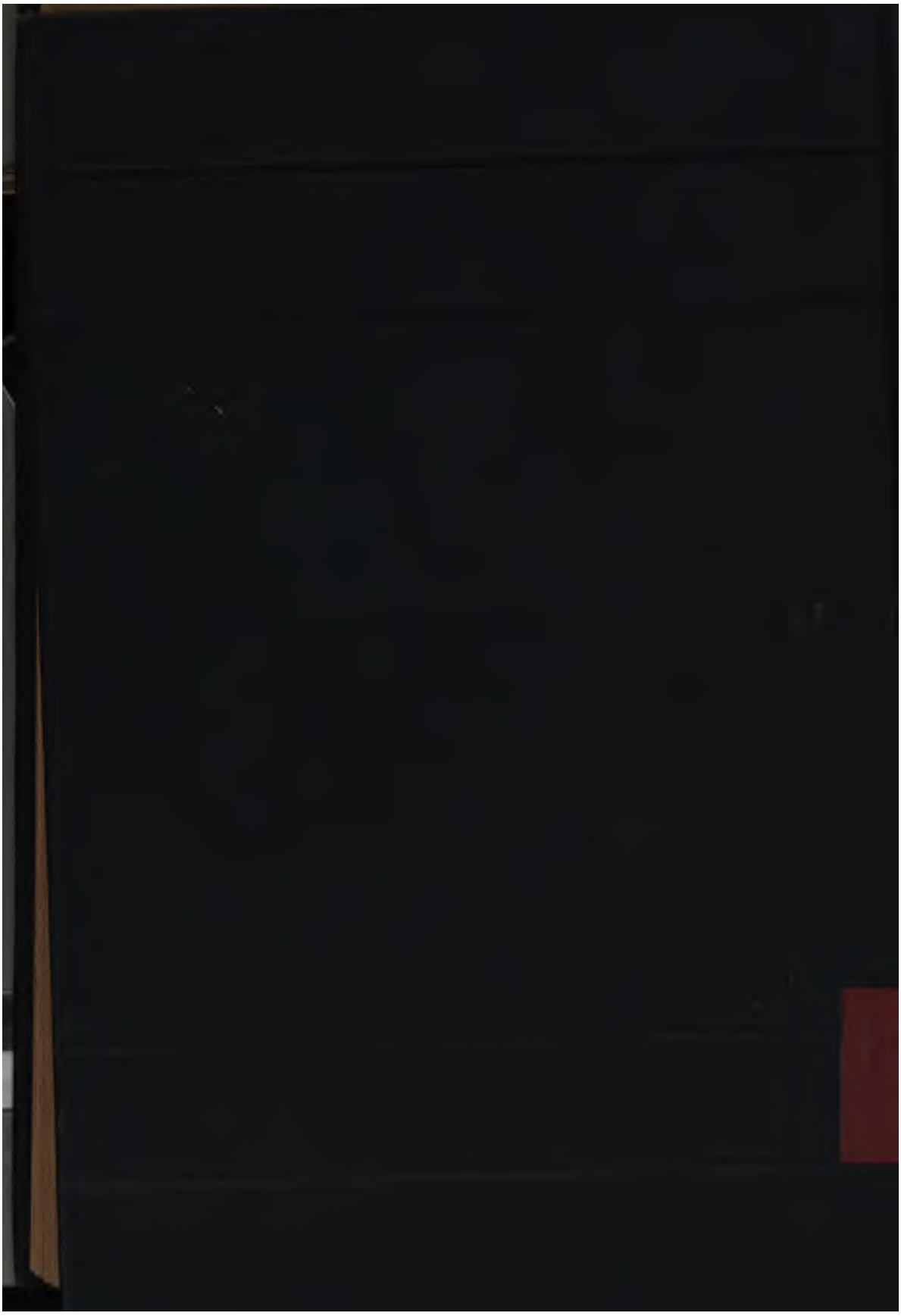
Telephone Wires, Transposition and Relative Location of Power and. (Illustrated.) 245
Telephony 1
Tendencies of Central Station Development. (Introduction by President Scott.) 403
Testing of Insulators. (*F. O. Blackwell.*) 239
Theory, Alternating-Current, Discussion of Some Points. (Illustrated.) 589
Theory of the Regulation of Alternators, Experimental Basis for. (Illustrated.) 497
Traffic, Telephone, Some Features of, and their Effect on Service .. 73
Train Lighting, an Axle Light System of. (Illustrated.) 163
Train-Lighting, Electric, Some of the Problems of 173
Train Lighting, Railway 129
Transmission Lines, Burning of Wooden Pins on High-Tension. (Illustrated.) 253
Transmission Lines, High-Tension 229
Transposition and Relative Location of Power and Telephone Wires. (Illustrated.) (*P. M. Lincoln.*) 245
Units and Central Stations, Multiple versus Independent Operation of. (Illustrated.) 425
Wooden Pins on High-Tension Transmission Lines, Burning of. (Illustrated.) 253

INDEX OF AUTHORS.

Abbott, A. V., Discussion 453
Abbott, W. L., Discussion 457
Abry, B. B., Discussion 222
Adams, Comfort A., Paper, 519; Discussion 579, 580
Allen, G. C., Discussion 67
Armstrong, A. H., Discussion 224
Armstrong, J. R., Communications 296, 582
Arnold, B. J., Discussion 457, 460, 461
Bedell, Mr., Discussion 317
Behrend, B. A., Paper, 497; Discussion 578, 582
Bibbins, J. R., Communication 193
Blackwell, F. O., Paper 239
Bliss, W. L., Paper, 133; Discussion, 180, 184, 186, 188, 211, 214, 219
Blodgett, George W., Discussion 182, 183
Bradley, Charles, Discussion 88
Browne, Sidney Hand, Communication 90
Buck, H. W., Discussion 290
Campbell, J. M., Discussion 223
Carhart, H. S., Discussion 179
Carlton, W. G., Discussion 307, 308, 460
Carty, J. J., Discussion 56
Chesney, C. C., Paper, 253; Discussion 278, 294
Corson, Wm. R. C., Discussion 266
Cory, C. L., Discussion 267
Cravath, J. R., Discussion 311, 460
Devereux, Washington, Discussion 305
Dudley, Chas. B., Discussion 209, 212, 213, 214, 218, 219
Dunn, Gano S., Discussion 580
Eglin, W. C. L., Discussion 216, 219, 469
Etheridge, H., Discussion 317, 465
Farnsworth, Arthur J., Paper, 163; Discussion 183
Floy, Henry, Communication 297
Foster, H. A., Discussion 471
Frankenfield, B., Discussion 317, 325
Franklin, W. S., Papers, 261, 589; Discussion 294
Garfield, A. S., Paper 569
Gear, H. B., Discussion 459
Gerry, M. H., Jr., Communication, 295; Discussion, 263, 275, 282, 289
Gherardi, B., Jr., Discussion 58
Gonzenbach, Ernest, Discussion 308
Grace, S. P., Discussion 84, 316, 317, 321
Hammer, William J., Papers 31, 331, 372
Hatch, A. H., Discussion 308
Hering, Carl, Discussion, 209, 213, 214, 218, 219, 305, 306, 307, 469, 471
Hewitt, Chas., Discussion 214, 306, 307, 474, 475
Hodges, Mr., Discussion 301, 306
Hodgkinson, Francis, Discussion 462
Hogan, C. W., Discussion 183
Huntington, H. L., Discussion 271
Hutchins, Jas. T., Discussion 306
Junkersfeld, Peter, Paper, 425; Discussion 454, 459
Karapetoff, V., Discussion 586, 587
Kinsman, F. E., Discussion 71
Klumpp, Jno. B., Discussion 219

Lardner, H. A., Paper, 407; Discussion..... 455
Latour, Marius, Communication..... 583
Lesley, Hugh, Discussion.....213, 214, 218
Lieb, Jno. W., Discussion..... 451
Lincoln, P. M., Paper, 245; Discussion, 220, 224, 276, 283, 288, 290, 305, 306, 317, 466, 586, 587
Lockwood, Mr. (Detroit), Discussion..... 183
Lockwood, Thomas D., Paper, 3; Discussion.....55, 70, 71
Lyndon, Lamar, Discussion.....179, 185
McElroy, James F., Paper, 197; Discussion,..... 189
McMeen, S. G., Paper..... 81
Mailloux, C. O., Discussion..... 287
Masters, A. H., Discussion..... 222
Matlack, E. D., Discussion..... 467
Mershon, Ralph D., Paper, 233; Discussion, 263, 266, 267, 271, 274, 275, 276, 278, 283, 289, 291
de Muralt, Carl L., Discussion..... 292
Olin, E. M., Discussion..... 587
Peck, Jno. S., Discussion.....220, 321, 587
Perrine, F. A. C., Discussion..... 299
Pickernell, F. A., Discussion..... 57
Pope, Ralph W., Discussion.....212, 213
Reed, Chas. J., Discussion..... 218
Rice, C. W., Discussion..... 465
Rugg, W. S., Discussion..... 453
Sanville, H. F., Discussion..... 307
Schmit, Mr., Discussion..... 587
Schwartz, Carl, Communication..... 461
Scott, Charles F., Papers, 1, 129, 229, 327, 403; Discussion, 55, 181, 182, 184, 185, 191, 263, 323, 441, 452, 467, 578, 579, 580
Sheldon, Samuel, Discussion.....56, 57, 58, 63, 67, 70, 274
Shepardson, George D., Paper..... 173
Sherwood, E. F., Discussion..... 63
Shock, T. W., Discussion..... 277
Skinner, C. E., Discussion.....287, 293, 312
Slichter, W. I., Discussion..... 225
Sloan, J. R., Discussion..... 184
Smith, W. N., Communication, 295; Discussion.....185, 273, 276, 294
Sniffin, Edw., Discussion..... 450
Snyder, R. A. L., Paper..... 93
Spalding, Ph. L., Discussion..... 219
Spencer, Paul, Discussion..... 474
Spencer, Thomas, Discussion..... 307
Sperry, Elmer A., Paper, 155; Discussion.....185, 187
Steinmetz, C. P., Discussion..... 225
Stern, Philip K., Discussion..... 456
Storer, N. W., Discussion..... 220
Stott, Henry G., Discussion.....184, 442, 456
Thomas, P. H., Discussion.....273, 278, 285, 319
Torchio, Philip, Paper, 417; Discussion.....293, 455, 456, 472, 474, 475
von Recklinghausen, Max, Discussion..... 181
Wagner, Herbert A., Discussion..... 444
Wait, H. H., Discussion..... 308
Waldron, F. A., Discussion..... 445
Waterman, F. N., Discussion..... 277
Waters, W. L., Discussion.....280, 580
Welz, Frank, Discussion..... 468
Williams, R. Neil, Communication..... 226
Williams, W. H., Discussion..... 84
Wolcott, Townsend, Discussion..... 452
Woodward, Cornelius W., Discussion..... 214
Woodward, F. S., Communication..... 296
Wray, J. G., Paper,..... 73

NON-CIRCULATING

98214, v.21, 1903
American institute of electrical engineers
Transactions

DATE	NAME	DATE
2-19-08		
2/-08		
1 11		
1912